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THE THEATER HIGH ALTITUDE AREA DEFENSE PROGRAM: AN INTERIM EXAMINATION OF ITS ACQUISITION STRATEGY

by

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THE THEATER HIGH ALTITUDE AREA DEFENSE PROGRAM: AN INTERIM EXAMINATION OF ITS ACQUISITION STRATEGY

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ABSTRACT

This thesis is an examination of the Theater High Altitude Area Defense (THAAD) program's implementation of the User Operational Evaluation System(UOES) acquisition strategy. The Missile Defense Act of 1991 imposed significant schedule risk on THAAD's development, necessitating the UOES strategy. The UOES risk management issues are analyzed using DOD's risk management guidance. This guidance incorporates some current methods, applications, and trends in using prototypes during development. Using this guidance, THAAD's tailored acquisition strategy is reviewed. From this review, lessons that have been learned from the program's experience are developed. The results show that as a result of programmatic risk the UOES strategy has resulted in a delay in fielding the full THAAD objective system.

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I. INTRODUCTION

A. BACKGROUND

1. History of Ballistic Missile Defense

Ballistic missiles were first used by Nazi Germany against Antwerp and London. At that ~~time~~, ballistic missile defense was technologically limited to air-burst artillery fire to deflect or destroy incoming missiles. During the Cold War period, the superpowers kept each other in check by refining the ballistic missile concept and building large numbers of inter-continental ballistic missiles (ICBMs). Their defenses consisted of nuclear air-burst interceptors, with reliance on the concept of Mutually Assured Destruction. In 1972 the United States and the former Soviet Union signed the Anti-Ballistic Missile (ABM) Treaty. This treaty placed specific limitations on the size, number, and speed of each nation's defensive capability. Today, missile defense is segmented into two broad categories. Strategic systems defend a continental-size area from inter-continental or sea launched ballistic missile attack, and theater systems defend a smaller region from ballistic missile attack. The ABM Treaty places most of its limitations on strategic systems.

Development of a United States strategic missile defense system has been an intermittent project for several decades. Portions of the technologies required for this military capability are available, but an integrated system does not now exist. Our current national strategy gives priority to developing and fielding theater missile defense (TMD) systems, while keeping the strategic systems in a Technology Readiness Program. This

strategy places emphasis on the greatest threat. As the threat to the United States grows, the National Missile Defense (NMD) system can be accelerated from a Technology Readiness Program. This strategy permits NMD fielding if needed, and allows the opportunity to leverage-in mature TMD technologies. This thesis is a case study of the acquisition strategy for the Theater High Altitude Area Defense (THAAD) system. THAAD is a high priority TMD system currently in development.

2. Ballistic Missile Threat

In the post-Cold War period, the threat of a large scale ICBM attack against the United States is practically non-existent. On the other hand, the medium range tactical ballistic missile (TBM) threat is diversifying, growing faster than ever, and can carry weapons of mass destruction. Today, more than 30 types of TBMs exist. Nineteen nations possess missiles that can carry a payload of 1,000 kilograms to a range greater than 300 kilometers [Ref. 1: p. 34]. A growing number of countries are working on missiles with ranges greater than 1,000 kilometers.

The PATRIOT missile system's role during Operation Desert Storm brought some public attention to TBMs and our severely limited defensive capability. During the Gulf War, once Iraq launched a TBM, the PATRIOT PAC-2 (PATRIOT Advanced Capability-2) missile was the only defense. The allied nations deployed almost every PATRIOT fire unit in the world to the region, but PAC-2 missiles provided only limited coverage for top priority political assets. Tactical and strategic assets were virtually unprotected.

TBMs are a threat to our forward deployed forces and the homelands of many of our allies. Given the current growth rate, a limited ICBM threat to the United States

homeland will reappear. The question, currently receiving much political debate, is how soon this threat will reappear?

3. Legislative Mandate

In response to the growing threat, Congress passed the Missile Defense Act of 1991. This legislation required abrupt new steps toward deployment of NMD and TMD systems. The Act, signed into law December 5, 1991, required the Secretary of Defense (SEC DEF) to have an operationally effective TMD capability by 1996. The law gave the SEC DEF 180 days to present a Department of Defense (DOD) plan to meet the 1996 deployment deadline. [Ref. 2]

Ballistic Missile Defense Organization (BMDO), formerly Strategic Defense Initiative Organization, is the DOD organization responsible for coordinating development of missile defense capabilities. In response to the 180 day mandate, BMDO planners reviewed the ballistic missile threat compared to our existing and future missile defense technologies. Because the ABM Treaty was a constraint on available options, all options were classified as treaty compliant or treaty non-compliant.

4. Options Available

One promising TMD option was THAAD. It appeared that THAAD would be effective against the growing threat and be treaty compliant. Additionally, THAAD could demonstrate a significant technology maturity to the NMD Technology Readiness Program. Figure 1 is the author's depiction of the situation BMDO faced in 1991. Threat capability is graphed in the background. It was ahead of our existing TMD capability, and it was growing at a steady pace. Enhancements to

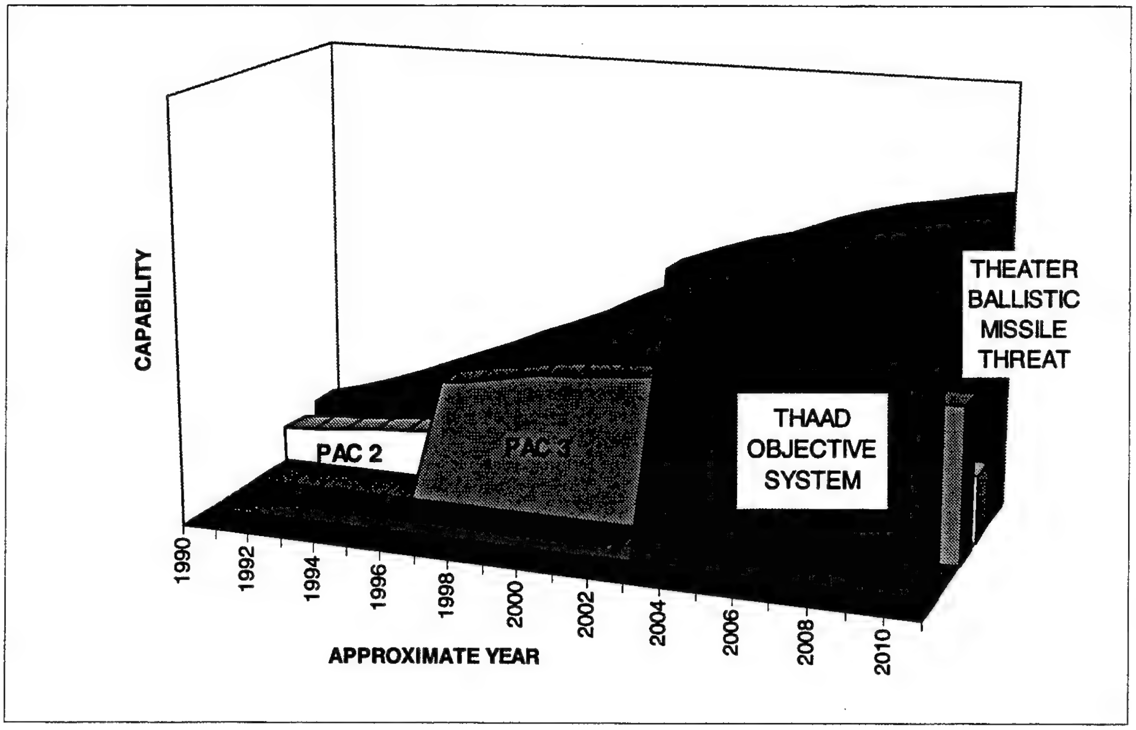

Figure 1. THAAD Acquisition Strategy - Traditional Approach

PATRIOT (i.e., PAC-3) would bring some defense against the threat, but a new generation weapon system was required to outpace the threat. Development of THAAD would provide a foundation for our capability to outpace the threat well into the next century. Under a traditional acquisition strategy, the Initial Operational Capability (IOC) of THAAD would be at least ten years away. This time frame was unacceptable to BMDO planners because it would not provide the urgently needed TMD capability for our forward deployed forces and many of our allies.

A traditional acquisition strategy could not meet the urgent need and fulfill the legislative mandate. Therefore, BMDO planners conceived the User Operational Evaluation System (UOES) strategy for THAAD. Figure 2 is the author's depiction of

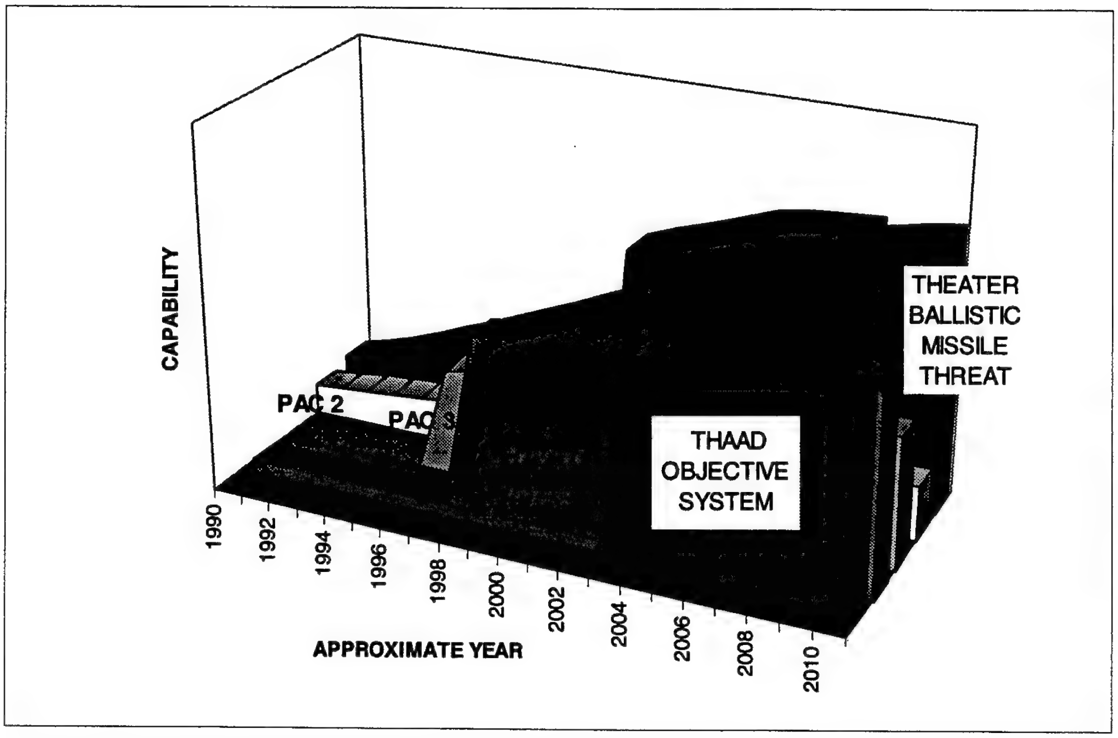

Figure 2. THAAD Acquisition Strategy - User Operational Evaluation System Approach

BMDO's innovative approach to meet the threat. This aggressive strategy produces an interim operational prototype, which may be used in a variety of ways to enhance the objective system. Additionally, the strategy provides for the prototype system to be available for deployment in the event of a national emergency. This aggressive strategy was a direct response to the Congressional mandate to rapidly develop a TMD capability.

B. OBJECTIVE

The objective of this thesis is to examine UOES as an innovative acquisition strategy. The author will examine trade-offs made within the program among cost, schedule, and performance. From this examination, lessons-learned will be identified that

will aid acquisition management personnel in making informed decisions about selection of a UOES acquisition strategy for future programs.

C. RESEARCH QUESTIONS

In pursuit of the objective of this thesis, the primary research question is: What are the lessons from the THAAD program that will be helpful to other acquisition managers in minimizing cost, schedule and performance risk?

The subsidiary research questions are:

1. What are the specialized requirements that drove the program to its operational prototype strategy?
2. What are the key THAAD risks, and how has the acquisition strategy addressed those risks?
3. What risks have been increased as a result of the strategy?
4. What advantages and disadvantages should acquisition managers consider before including an operational prototype in an acquisition strategy?

D. SCOPE

THAAD is in the final year of a four year demonstration and validation (DEM/VAL) contract. Flight test five of 14 DEM/VAL flight tests took place on March 22, 1996. Final data analysis of this test is still pending. Therefore, this thesis is based on observations prior to test five. Because this is an ongoing program, a complete study of the effectiveness of the acquisition strategy is not yet possible. However, an examination of the decision making process and the dynamics in the acquisition environment that have thus far influenced the THAAD program is beneficial.

Analysis is of the THAAD program issues only. THAAD will be a major element in the Active Defense pillar of Joint Theater Missile Defense (JTMD) doctrine. When relevant, there is some comparison of THAAD issues to other programs facing similar situations.

E. LITERATURE REVIEW AND METHODOLOGY

This thesis is a case study of the acquisition strategy used in the THAAD program. First, there is a background review of DOD risk management; this is followed by a review of some current uses of prototypes in systems development. Next, the THAAD system and its innovative acquisition strategy is outlined. This background information is then used to conduct an analysis of risk management issues related to the acquisition strategy.

The author obtained background information from DOD reports, General Accounting Office reports, professional papers, DOD publications, and THAAD program documents. These documents were found through research in the Naval Postgraduate School Library or from Defense Logistics Studies Information Exchange. Much information was obtained through visits to the THAAD Project Office (TPO) and to the THAAD prime contractor, Lockheed Martin Missiles and Space Company (LMSC).

F. DEFINITIONS, ACRONYMS, AND POLICY CHANGES

The author uses standard DOD and Army definitions for acquisition management and missile defense terms. Appendix A provides: (1) the definition of terms that have a designated meaning in this thesis, (2) a consolidated designation of the acronyms.

Appendix B provides a summary of some recent trends related to risk management terminology.

The author assumes the reader is generally familiar with the Department of Defense Acquisition Management Process. This document is based on terms and policies in effect in 1991 at the initiation of the THAAD program. Table 1 cross references the old and new terms for acquisition phases as they are found in the 5000 Series of Department of Defense Instructions.

Old 5000 Series (FEB 1991)	**New 5000 Series** (MAR 1996)
Concept Exploration & Definition	Concept Exploration
Demonstration & Validation	Program Definition & Risk Reduction
Engineering & Manufacturing Development	Engineering & Manufacturing Development
Production & Deployment	Production/Fielding, Deployment, and Operational Support
Operations & Support	

Table 1. Cross Reference of Old and New Terms used for Acquisition Phases

II. PROTOTYPING AS A RISK MANAGEMENT STRATEGY IN THE ACQUISITION PROCESS

A. PURPOSE

An acquisition strategy sets a course for a program to follow throughout its life-cycle. A PM should tailor the strategy to address unique risks or unknowns of the program. A strategy's goal is to insure a program delivers a useable, supportable, and reliable product within acceptable constraints of cost, schedule, and performance. This chapter first examines how DOD acquisition strategies typically approach risk management. Second, it overviews some current methods and applications of prototyping. Finally, this chapter reviews some advantages and disadvantages of prototyping. This chapter provides a framework for an analysis of UOES risk management issues in this thesis.

B. RISK MANAGEMENT IN THE DEPARTMENT OF DEFENSE

1. Definitions

The Defense Systems Management College (DSMC) defines risk as "the probability of an undesirable event occurring and the significance of the consequence of the occurrence." [Ref. 3: p. 3-1] The first factor in this definition, probability of occurrence, is associated with the prioritization of risks. Program managers (PMs) should not overlook the second factor, significance of the consequence. Consideration of the impact of an occurrence can enable a PM to progress away from strictly prioritized risk management. When a PM considers both factors together, the result is a more

realistic expected value of the risk. With this more accurate assessment, the PM can make more informed decisions. For example, the PM may choose to accept risks where the probability of occurrence is high, but where the consequence of occurrence is minimal. He or she can then more efficiently allocate resources toward the areas where the expected pay-off is higher or total risk is lower.

2. Types of Risk

DSMC lists five facets, or types, of risk. [Ref. 3: pp. 3-3 - 3-6]

a. Technical Risk

This type of risk includes the complexities associated with developing a new design to provide a higher level of performance or reconfiguration of one or more mature designs for a new application. The predominant causes of technical risk are the user's constant demand for greater performance and the high rate of technology developments. A design that has high technical risk today may be less risky in the future when the designers have access to improved resources and processing techniques. Some major sources of technical risk are component interfaces, software design, requirements changes, and demand for more performance.

b. Programmatic Risk

This type of risk refers to external forces that influence a program's direction. External forces are outside a PM's span of control. Programmatic risks stem from variance between the environment for which a PM planned and the actual environment. Some major sources of programmatic risk are political advocacy, changing funding profiles, and regulatory changes. A sudden shift in any of these external sources

may produce a very disruptive ripple through a program. This disruption may result in an inability to achieve desired performance within acceptable cost or schedule.

c. Supportability Risk

This type of risk is associated with fielding and maintaining systems that are in development. Although a system is technically producible and has low programmatic risk, unique technologies or maintenance requirements may result in a life-cycle cost that is unaffordable. Some major sources of supportability risk are reliability, maintainability, interoperability, transportability, and training.

d. Schedule Risk

Schedule risk is the probability that the actual time required to achieve specific objectives will exceed the allocated time and the significance of this occurrence. Some critical program management schedule issues are: the length of time required to adequately resolve technical issues, time limitations associated with appropriated funds, and system readiness to test when facilities are available.

e. Cost Risk

Cost risk is a product of the probability and impact of an actual cost that exceeds the budgeted cost baseline. In turn, increased risk in other areas has a cumulative effect on cost risk. Solutions to technical and supportability issues often require additional funds to resolve. When a PM accelerates or stretches a schedule, there are adverse effects on cost. An increased cost estimate tends to decrease political support. This fluctuation may result in increased scrutiny, a funding profile that is stretched over a longer period, or a fixed funding profile with a corresponding reduction in the number of

units bought. Because cost risk is an indicator of risk in other types of risk, cost estimates are harder to define when there is significant risk in other areas.

3. Risk Management Structure

There are four separate but related activities that are part of the DSMC risk management structure. This structure helps a PM to develop an effective and responsive risk management plan.

a. Risk Planning

The purpose of this activity is to eliminate, minimize, or contain the effects of undesirable occurrences. Risk is present, to some degree, in every program at every stage of development, production, or sustainment. Therefore, risk planning should be a continuous process, and personnel from every functional area should contribute to the process. PMs have a wide degree of freedom to tailor their Risk Management Plans to their programs' unique needs. Most PMs formally assess their risks at least quarterly. From this formal assessment, PMs allocate resources, as necessary, to keep their programs within acceptable limits. [Ref. 3: p. 4-3]

b. Risk Assessment

This activity identifies risks and produces a preliminary quantification of their probability and impact. During this activity the most critical step is identification. This step entails a thorough phase by phase consideration of the program to seek out what functions or technologies will be a risk to the program. The initial quantification step makes a relative ranking of risk areas. [Ref. 3: p. 4-8]

c. Risk Analysis

This activity builds on the preliminary assessment and produces an in-depth sensitivity analysis of the areas having the greatest expected impact. Risk analysis is essentially a war-gaming of various risk handling courses of action to determine expected consequences. A key output of this analysis is a watchlist; this is a recognizable list of critical risks in the program. A watchlist addresses potential risk events and the areas impacted. [Ref. 3: p. 4-9]

d. Risk Handling

This activity includes the actions taken to address the risk issues that were previously identified during a risk assessment. There are four management techniques to influence the expected impact of a risk. [Ref. 3: p. 4-10 - 4-13]

- *Risk avoidance* includes basing a design on a low risk technology; however, a strict risk avoidance policy results in a constraint on design flexibility and its ability to meet the user's demand for greater performance.

- *Risk control* is the most common and most involved of the handling techniques; it is a process of continuous monitoring and refinement of the program. To carry out risk control, a PM establishes risk acceptance criteria and measurable thresholds for risk. He or she uses these criteria and other relevant metrics to monitor the watchlist areas and better determine their program's status in terms of risk.

- *Risk assumption* is a calculated decision to accept the consequences if the undesirable event occurs. Not all risks can or should be avoided. For example, schedule pressures may influence a PM to assume technical risk.

- *Risk transfer* is similar to assumption, but using this technique a PM shares some of the risk with another interested party. Co-development of a system is a method to share a risk with other potential users. A PM may also transfer a portion of the program's risk to the contractor by the type of contract, performance incentives, or a warranty.

C. PROTOTYPING AS A RISK HANDLING ACTIVITY

1. Prototype

A prototype is a model of a system design used to aid in development of follow-on refined versions of the same system. A prototype may be full scale or reduced size. Reduced size prototypes are based on assumptions about proportionality and scaling that should be validated before commitment to a particular design. A model may be of a complete system, or it may be a model of certain high risk modules of a complete system. A model may be a fabrication of a portion of a system that focuses on immature and high risk elements. It may not be necessary to integrate mature and low risk elements into the structure. The purpose of a prototype is to answer four questions:

- Is the concept feasible?
- Does the design work the way it is supposed to work?
- Does the system provide a useful military capability?
- Does the design meet the performance requirement?

Answers to these questions provide feedback on technical and supportability risks. Armed with this information, the concerned parties can make more informed choices regarding risk management structure. This definition of prototyping and the focus of these questions are key to understanding the usefulness of prototypes. [Ref. 4: p.2]

In response to a risk assessment, PMs may consider prototyping. Prototyping may be a cost-effective risk handling activity to update and refine any assumptions made during risk assessment and risk analysis. Prototyping may help avoid premature commitment of production resources.

Prototyping is a common acquisition management technique that provides feedback on initial assumptions made in risk assessment and risk analysis. Understanding technical risk is an immediate beneficiary of prototyping. Experience gained from operating a prototype can also define supportability issues. Schedule and cost indicators can be defined, and because prototyping requires a partial development, these risks may be reduced for following development phases. Demonstrations of a system's increasing effectiveness to sponsors may help reduce programmatic risk. Each of these sources of feedback enables better decision making in risk planning and risk handling.

2. Prototyping Methods

Information-age technology has produced a wide range of prototyping methods. Traditional methods of prototyping range from hand carving scaled models out of relatively inexpensive materials, to machining required materials at full scale and with full functionality. Inexpensive scaled models provide considerably less feedback than full scale operational models. Cost of the prototyping effort increases as the degree of functionality increases. For some developments, traditional methods of prototyping are too expensive and require more time than the expected feedback is worth. However, many limitations associated with traditional methods of prototyping are quickly fading. An explosion of new technologies is expanding the limits. New prototyping technologies center around three interrelated prototyping methods, which are rapid component prototyping, software prototyping, and virtual prototyping.

a. Rapid Component Prototyping

Rapid component prototyping is an extension of progress in computer aided design (CAD). CAD produces digital specifications for a part; then an automated pattern-making machine uses that digital design. Master patterns for castings and metal molds are made with little or no hard tooling. Rapid component prototyping takes a matter ~~of~~ days, whereas traditional hard tooling could take months. This time-saving advantage enables developers to experiment with various designs and materials.

Rapid component prototyping produces a physical product. Engineers pass the item to users and sub-contractors; this aids in communication of expectations for form, fit, and function. A physical example more effectively communicates technical ideas to all audiences than traditional methods such as technical drawings. In the 1990s, stereolithography (SLA) is a popular rapid component prototyping process among aerospace contractors.

> SLA units build plastic parts by mathematically slicing CAD designs into thin cross sections. An ultraviolet beam traces each layer in a vat of photosensitive chemicals that solidify as they are irradiated. After each layer is completed, the elevator holding the part moves down about five mils and the next layer is solidified on top of it. SLA machines produce parts at a rate of one vertical inch every two hours.[Ref. 5: p. 19]

Rapid component prototyping enables use of better materials in the process. Improved resins, molds, and adhesives result in rapid prototypes that more closely resemble the objective product's characteristics. Other terms industry uses for rapid component prototyping technology are desktop manufacturing, free-form manufacturing, and 3-D printing systems.

b. Software Prototype

Application of computer aided software engineering (CASE) techniques to a previously manual software development process makes rapid software prototypes possible. Communication of needs between user and designer is probably most difficult in software development. Software is an abstract product that relies heavily on precise definitions, functions and interfaces; these characteristics compound the software requirements communication problem.

The literature addresses a variety of software design typologies, and some software prototypes are called rapid software prototypes. Two dominant classes of software prototypes are:

- Expendable - the code is discarded after it has helped to address the user's requirements, and the prototypes are not reused in the final system.
- Evolutionary - the prototypes are iteratively built upon to achieve the objective system, and prototypes are reused in the final system. [Ref. 6: p.4]

To overcome difficulties in communication of requirements, software prototype developers produce a very limited prototype of what they think the user wants. This original version prototype may be expendable or evolutionary. It usually contains a very small percentage of the number of lines of code, objects, or feature points that the objective system will contain. Users try the software to verify that developers have addressed their problem. Users make their comments, and developers incorporate these comments to refine the product to better fit user expectations. This process continues until user and developer have addressed all the issues and reached an agreement on what is a realistic product.

A typical software prototype development process is:

- Identify basic requirements: identify essential features; completeness is not important.
- Develop a working prototype: this should be accomplished very quickly (e.g., an "overnight" development of a prototype).
- Implement and use: hands-on use of the system provides experience, understanding, and evaluation.
- Revise and enhance: undesirable or missing features identified by the user must be corrected.[Ref. 6: p. 7]

An example of software prototyping comes from Jet Propulsion Laboratory (JPL) at California Institute of Technology. JPL established a Flight Projects Office Information Systems Testbed (FIST) to determine if it was possible to construct a seamless networked telemetry processing system for use on space missions. JPL's guidelines to the FIST team were to use commercial off the shelf (COTS) items, use emerging industry standards for protocols and interfaces, and maximize portability across different vendors' platforms. JPL's goal was to enhance its ability to efficiently take advantage of an explosion in new hardware technology. Previously, infusion of new hardware required a major redesign of JPL's telemetry processing systems. The FIST team used an evolutionary prototype for the new architecture. The team selected this approach for risk control, shortened development cycle, and accelerated technology transfer. Two JPL engineers commented:

> Unlike a throw-away prototype, which is useful when many of the aspects of a design are untried, evolutionary prototypes are robust in design and are built upon a foundation that is well-understood. It is a fast and cost-effective method of proving out new concepts and accelerating their simultaneous integration into operational environments and next-generation products.

> Evolutionary prototyping concludes in the worst case with a small-scale, limited distribution product for operational environments, and in the best case leads to full-scale development of multi-user and multi-mission systems.[Ref. 7: p. 466]

In summary, software development is a difficult and complex topic. Software prototyping is an effective and widely used development tool. Use of software prototypes allows developers to avoid investment of thousands of man-hours that produces a grand software design, only to find their product is far from user expectations.

c. *Virtual Prototype*

Virtual prototyping is an extension of technologies that make both component and software prototyping possible. Once a system design is represented in a useable digital format, as required for component prototyping, a prototype of the associated system's software can operate from that digital database as if a physical system is on-line.

The DOD defines a virtual prototype as:

> A computer-based simulation of systems and subsystems with a degree of functional realism comparable to a physical prototype. Virtual prototyping is the process of using a virtual prototype, in lieu of a physical prototype, for test and evaluation of specific characteristics of a candidate design [Ref. 8: p. 26].

An in-orbit repair of the Hubble Space Telescope (HST) was possible because of virtual prototyping. A problem with HST arose when, shortly after deployment to its earth orbit, some of its ultra-sensitive lenses and mirrors failed to focus. National Aeronautics and Space Administration (NASA) scientists had a one-shot opportunity for an in-orbit retrofit. Space Shuttle astronauts could deliver corrective

mirrors to the telescope, but HST's design was too small for astronauts to work inside its interior case. Astronauts could only place repair parts on motorized arms on the exterior of HST. Engineers had to design corrective mirrors within the motorized arms' ability to place them in a precise position inside the compact telescope. NASA had to be certain the retrofit parts were sufficient to correct the improper focus and, at the same time, be within the motorized arms' highly specialized capability. NASA turned to virtual prototyping to define their limitations.

> Such a prototype would be an accurate 'working model' of the Corrective Optics Space Telescope Axial Replacement (COSTAR). It would exist not as physical hardware but as numbers in a computer memory representing COSTAR's dimensions, optical characteristics, and the range of motion of all its moving parts.[Ref. 9: p. 34]

A virtual prototype permitted NASA's engineers to perform tasks that otherwise would have been impossible. It allowed engineers to "look" inside the HST, from any angle with unrestricted access. NASA also experienced some spin-off advantages from virtual prototyping. For example, they found it very beneficial in cross-functional communication of specifications and interaction of intricate designs. In general, giving teams of engineers skilled in separate disciplines visual access to each other's designs helped minimize errors. [Ref. 9: p. 38]

3. Applications of Prototyping Methods

a. Competitive Prototypes

PMs can use prototypes to compare suitability of competing developers' designs. Competing developers receive the requirement, information about testing conditions, and evaluation criteria. They design and produce their best effort, then a

Source Selection Evaluation Board (SSEB) evaluates the competitors' prototypes to determine the most suitable design.

DOD Instruction 5000.2 required major defense acquisition programs to contract for competitive prototypes during DEM/VAL. The purpose of this requirement was to use competition during early design to help develop one or more different design approaches. The milestone decision authority (MDA) could waive the competitive prototype requirement. A waiver had to be based on a cost benefit analysis that indicated competitive prototyping increased technical, supportability, and programmatic risks more than it decreased cost and schedule risks.*

The U.S. Air Force F-22 Advanced Tactical Fighter is a highly visible example of a competitive prototype strategy. The PM funded two competing contractor teams to demonstrate high technical risk prototypes. They could use their own mixture of off-the-shelf equipment and new technologies to control those risks. The source selection authority (SSA) encouraged contractors to demonstrate additional technologies they thought would enhance the aircraft's mission or control risk. Competitors submitted their pre-test estimates of how well they thought their designs would perform. The SSA used the accuracy of these self-assessments to help determine which contractor team had the best control over its design process.[Ref. 10: p. 8]

* Since THAAD's Acquisition Strategy was approved at its 21 January 1992 Milestone I Decision, the DOD Instruction 5000.2 was revised in March 1996. This revised version allows more flexibility in this area. It now advises "Competitive prototyping and competitive alternative sources shall be used where practicable."

b. Advanced Concept Technology Demonstration

In June 1994, DOD initiated Advanced Concept Technology Demonstration (ACTD) programs. The purpose of these applications of prototyping is to increase the pace at which state-of-the-art technologies get to users. The ACTD program is not itself a prototyping method, but developers may employ one or more prototyping methods to demonstrate an available technology. Through the prototype users:

- Can experiment with the technology in their operational environment for up to two years.
- Develop a better early understanding of how the technology can influence their tactics, techniques, and procedures.
- Can influence the design while it is still fluid.

An ACTD is not a formal acquisition program, but if the demonstrated capability is beneficial to users, it may become a formal program. Some DOD guidelines for ACTD selection are:

- Technology should address a major operational need.
- Technology offered should be sufficiently mature that risks are minimal.
- Users expect a deliverable and affordable system.
- Demonstration should take no more than three years.
- Developers identify, understand, and accept the risks.
- Residual prototypes receive two years of funding after the demonstration.
- Sponsor is fully committed to participation.

There are three possible outcomes for an ACTD:

- User determines the technology does not meet their need or is not suitable.
- User keeps residual equipment and does not request further acquisition.
- User formally requests acquisition of the technology. [Ref. 11: p. 5]

The ACTD program is an improvement over its predecessor, the Advanced Technology Demonstrations (ATD) program. Options available for the Medium Altitude Endurance Unmanned Aerial Vehicle (UAV) highlight differences.

> As an ATD this program would build two or three air vehicles, test the system, demonstrate it to users, and then leave them without the new capability. Under the new ACTD program, a total of 10 UAVs will be procured to provide a militarily significant quantity for user evaluation and to assure a residual capability. This could offer important benefits in today's unsettled world. [Ref. 12: p. 24]

D. PROTOTYPING AS PART OF AN ACQUISITION STRATEGY

A PM must decide when to use prototyping to handle risk. Several recent studies have provided some indicators that can aid in this decision. This section reviews two of those studies.

1. Institute for Defense Analysis Prototyping Study

A new program can benefit from the experience of programs that have made it to production and deployment. One source of empirical evidence is a 1991 Institute for Defense Analysis (IDA) study of 51 major defense programs during 1971 - 1991. Of the 51 programs, 17 included development of a complete system prototype. The other 34 programs did not include development of either complete system, partial system, or sub-system prototypes. [Ref. 13: p. A-2, A-3]

The IDA study recommended prototyping for systems that involved:

- new performance or manufacturing technologies for the contractor(s).
- high cost per unit and large production quantities.
- long lead time or high cost to correct potential unforeseen problems.

Figure 3 represents an average of cost data from the 51 programs in IDA's study. This analysis indicates investment in prototyping helps to control cost risk. Each bar represents an average ratio of actual cost to estimated cost. The graph groups the ratios by prototyped and non-prototyped systems during development and production.

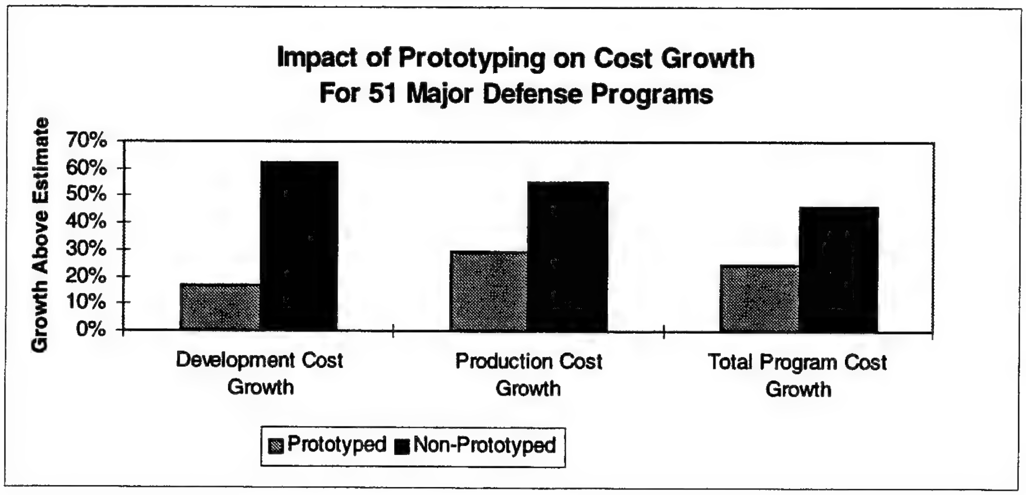

Figure 3. Impact of Prototyping on Cost Growth, After Ref. [13]

This graph indicates that both development cost growth and production cost growth were significantly less for programs that prototyped. Prototyping had more impact on development cost growth than on production cost growth.

Figure 4 suggests prototyping tended to increase schedule risk. This graph displays the average of actual months from Milestone I (MS I) and Milestone II (MS II) to initial operational capability (IOC). Practically all schedule impact occurred during DEM/VAL. On average, after a MS II decision, there was no significant difference between the programs that prototyped or those that did not prototype.

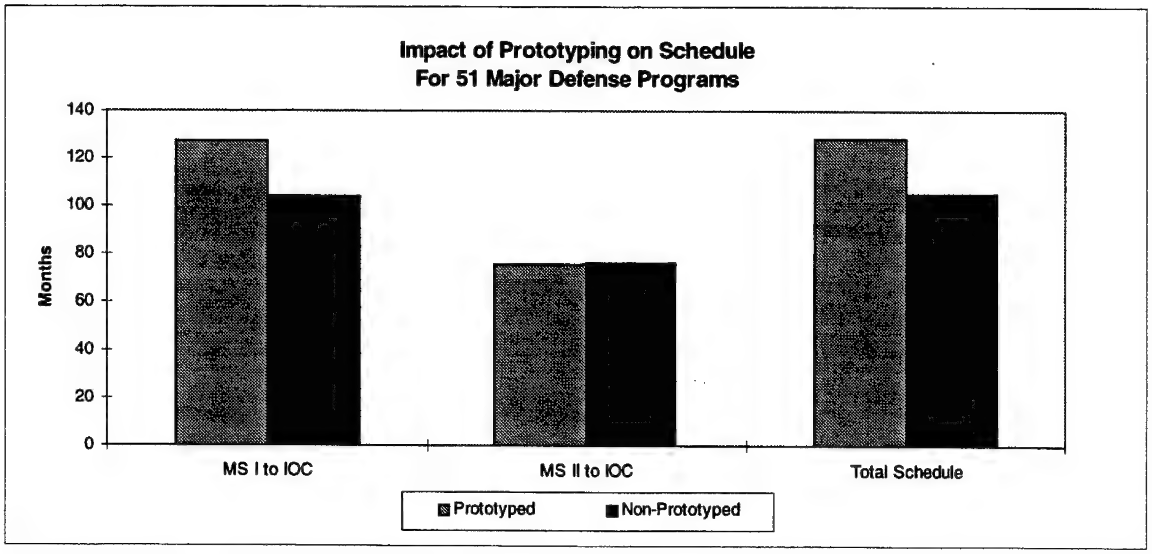

Figure 4. Impact of Prototyping on Schedule, After Ref. [13]

The author's analysis of data on the 51 programs listed in IDA's study reveals further evidence for the effectiveness of prototyping. The statistics in Table 2 indicate that prototyping cost additional money up front, but the investment paid big dividends in the form of less cost risk. More importantly, cost risk in the prototyped programs was more predictable. The 17 programs that prototyped experienced an average cost growth of 25%. The 34 programs that did not prototype experienced an average cost growth of 46%. This statistic alone indicates a major advantage of prototyping. However, the difference between the standard deviations of total cost growth reveals a more valuable advantage of prototyping. A .25 standard deviation for the 17 programs that prototyped versus a .57 standard deviation for the 34 programs that did not prototype indicates a significant reduction in uncertainty in cost growth.

Risk Management Metric	Prototyped	Non-prototyped
Number of Programs	17	34
Mean Total Cost Growth (Above Estimate)	25%	46%
Standard Deviation of Total Cost Growth	.25	.57
Mean Months From MS I to IOC	127	104

Table 2. Summary of Program Results

2. RAND Corporation Prototyping Study

RAND Corporation produced a 1992 prototyping study for the Under Secretary of Defense for Acquisition & Technology (USD(A&T)). This study is based on experience of weapons programs from 1960 to 1991, and during most of this period only traditional prototyping methods were available. (Rapid component prototyping, software prototyping, and virtual prototyping methods are recent trends, and their impact is not separately identified.)

The RAND study suggests the advantages of prototyping in general are:

- Identifies critical system integration issues; *decreases technical risk.*
- Permits more accurate cost, schedule, and performance estimates; *decreases cost, schedule, and technical risks.*
- Reduces cost consequence of proceeding into next phase with poor design; *decreases cost, technical, and supportability risks.*
- Allows necessary design changes to be identified early; *decreases technical and supportability risks.*
- Helps communicate specifications and intricate designs; *decreases technical risk.*

The RAND study also suggests the disadvantages of prototyping in general are:

- Adds two years, on average, from program initiation to IOC; *increases schedule risk.*
- Increases preliminary costs; *increases early cost risk.*
- Delays major funding commitment; *increases programmatic risk.*

The RAND study concluded that some form of prototyping is almost always appropriate. It found that prototyping will generate information to improve the quality of decision making in an environment of risk and uncertainty. [Ref. 14: p.73]

E. CHAPTER SUMMARY

This chapter is the framework for an analysis of THAAD's acquisition strategy and its risk management issues in Chapter IV. The chapter reviewed: (1) DSMC's approach to risk management in acquisition strategies, (2) some current methods and applications of prototyping, and (3) two recent studies regarding the role of prototyping in weapon system development. The recent advances in prototyping methods should enhance the advantages and reduce the disadvantages of prototyping. These advances should make prototyping more accessible and valuable in DOD acquisition.

III. THEATER HIGH ALTITUDE AREA DEFENSE SYSTEM

A. PURPOSE

This chapter provides a description of the THAAD system. This description is generally based on program accomplishments and future plans through DEM/VAL flight test five, which took place in March 1996. It describes: (1) plans for how THAAD will be used in an operational deployment, (2) the system's four major subsystems, and (3) the major cost, schedule, and performance differences between the operational prototype and the objective system. This knowledge of THAAD is essential for understanding the analysis of THAAD's acquisition strategy in Chapters IV and V.

B. OPERATIONAL CONCEPT

The U. S. Army Program Executive Office (PEO) for Missile Defense is developing THAAD as the upper tier of the two tiered Active Defense pillar of joint theater missile defense. THAAD's Operational Requirement Document (ORD) calls for near leak-proof defense, which will provide high confidence of threat intercept. [Ref. 15]

THAAD firing batteries will function in an operational deployment as displayed in Figure 5. The system has several notable features, which include:

- Autonomous operations or joint operations.
- Early warning and threat cueing to lower tier assets.
- Remote launch capability.
- Hit-to-kill technology.
- Shoot-look-shoot capability. [Ref. 16]

The system may operate in an autonomous mode, or it may operate with external BM/C3I systems. Among these external interfaces may be an Air Force Command and

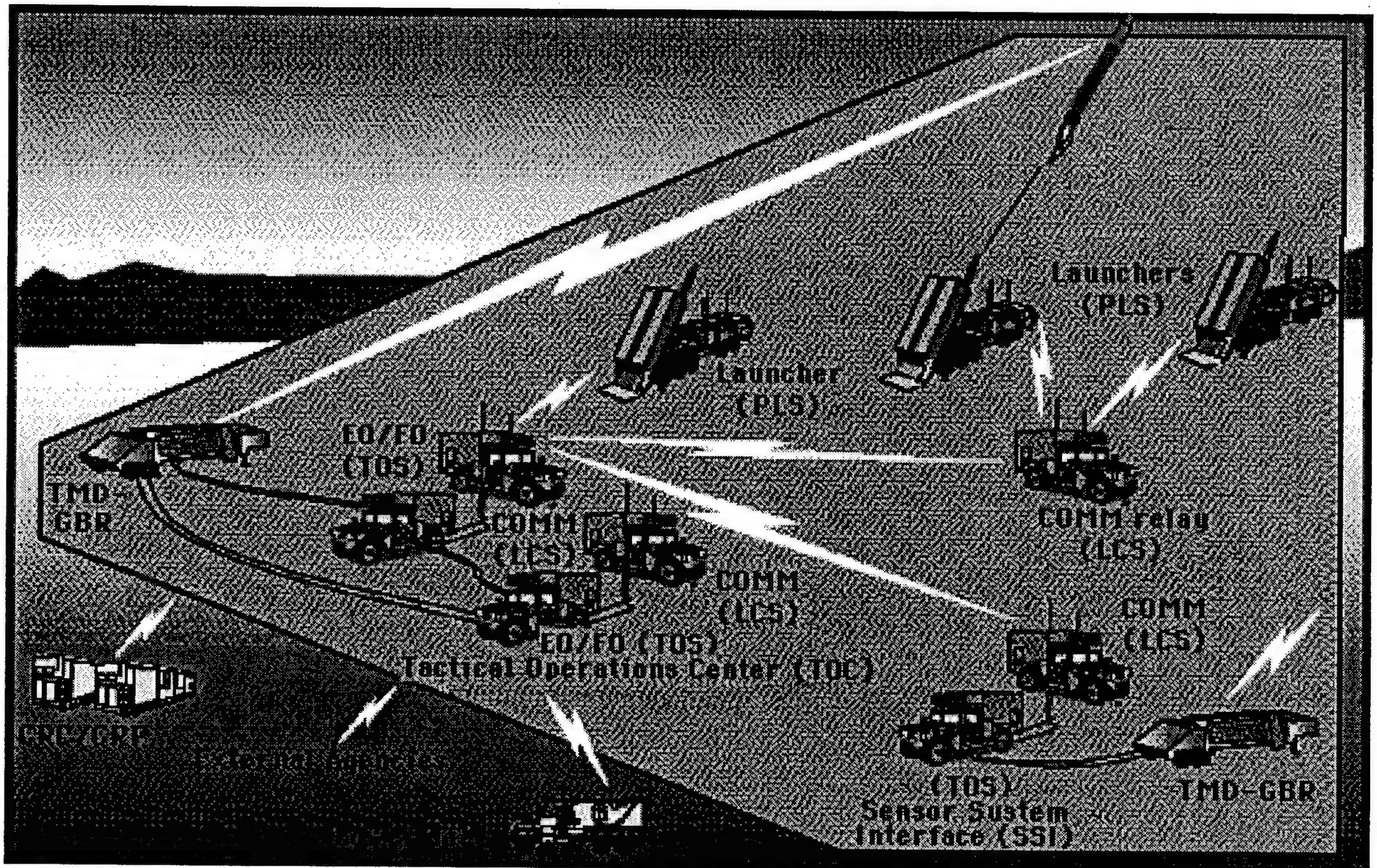

Figure 5. THAAD Operational Deployment. From Ref. [16]

Reporting Center (CRC), the Joint Tactical Ground Station (JTAGS), or a Force Protection Tactical Operations Center (FPTOC)[Ref. 17]. In either mode of operation, the system will provide sufficient range to intercept incoming ballistic missiles up to the edge of the earth's atmosphere.

THAAD will also provide critical early warning to a lower tier missile defense. Lower tier systems are generally *point* defense systems that provide much less coverage than THAAD's *area* coverage. The primary land-based lower tier system is PATRIOT PAC-3, and it may also include Medium Extended-range Air Defense System or an enhanced U. S. Marine Corps HAWK.

Internally, the tactical operations center for THAAD uses two Battle Management/Command, Control, Communications, and Intelligence (BM/C3I) shelters for force operations (FO) and engagement operations (EO). Multi-use Launcher Control Stations (LCS) provide communications links to remote launchers, which widens THAAD's area of coverage.

The missile uses hit-to-kill technology to destroy its target. THAAD's interceptor does not have a warhead, but it relies solely on its ability to find, lock on, and destroy its target using kinetic energy.

THAAD has a shoot-look-shoot capability. This simultaneously enhances lethality and missile conservation by making a hit or kill assessment after an initial shot. With this assessment the BM/C3I element can determine if the interceptor destroyed its target. If needed, a second interceptor can then be launched.

C. EQUIPMENT OVERVIEW

THAAD Project Office (TPO) is developing two distinct products. To meet the legislative mandate, a UOES package will be the first developed and delivered product, but an objective system is the ultimate product. Table 3, at the end of this chapter, summarizes the cost, schedule, and performance differences between the two products.

This acquisition strategy meets the urgent need for fielding increased TMD capability. The UOES package also supports the achievement of THAAD's operational requirement by helping to achieve a more suitable objective system. Both UOES and the objective system have four major subsystems, consisting of launcher, missile, TMD Ground Based Radar (GBR), and a BM/C3I element. These subsystems interface via a complete software package, which is approaching one million lines of code, primarily in the Ada programming language. (The focus of this introductory chapter is on equipment.) [Ref. 16]

1. Launcher

A tactical launcher subsystem (Figure 6) is mounted on a standard Palletized Load System (PLS) truck. Use of the PLS truck allows for autonomous reload of eight missile rounds per pallet. Flight test vehicles (FTV) one through four used a non-tactical interim launcher, while the remaining ten flight tests will use tactical launchers. Users already have daily access to the first PLS launcher, which has successfully endured a 300 mile off-road durability test. This first launcher also supported FTV five. Three more launchers will be produced under the DEM/VAL contract, and all four will be part of the UOES package. [Ref. 16]

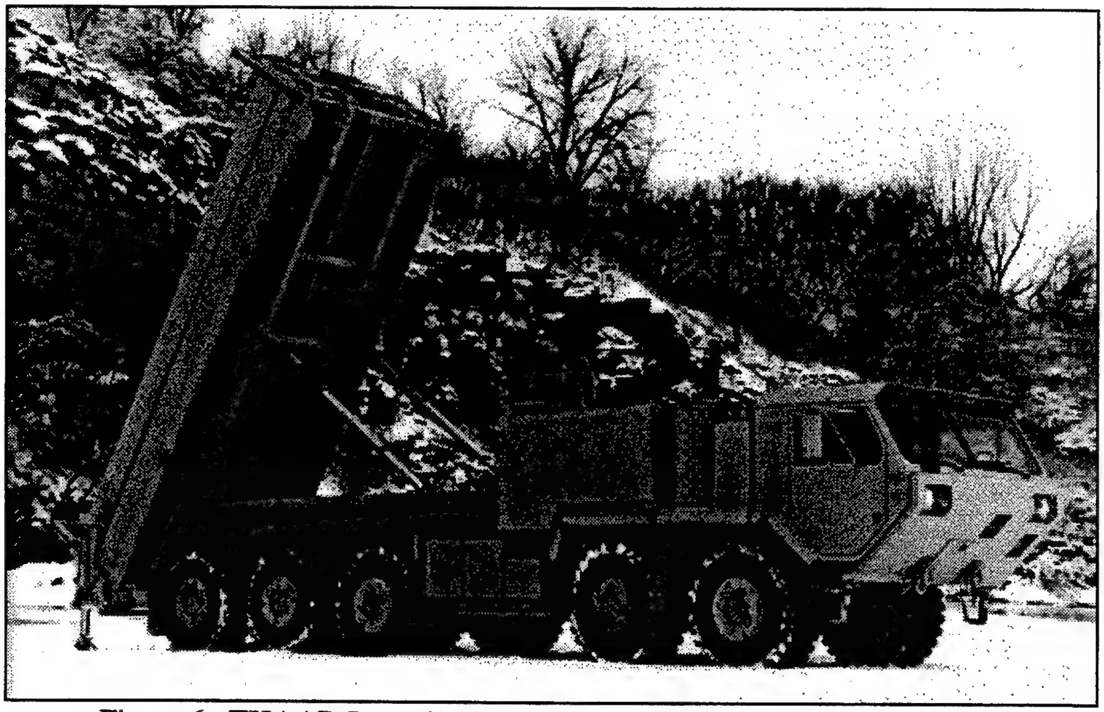
Figure 6. THAAD Launcher Mounted on a PLS Truck, From Ref. [16]

2. Interceptor

THAAD's missile subsystem is composed of three subsystems. These critical components are missile canister, propulsion system, and kill vehicle (KV). Figure 7 shows the interceptor at the beginning of the boost phase of flight. After assembly, a missile is housed in its hermetically sealed canister which provides protection during storage and shipment. The graphite epoxy canister also serves as a launch tube. Once sealed in its canister, a missile is a certified missile round, which requires no maintenance for a ten year service life.

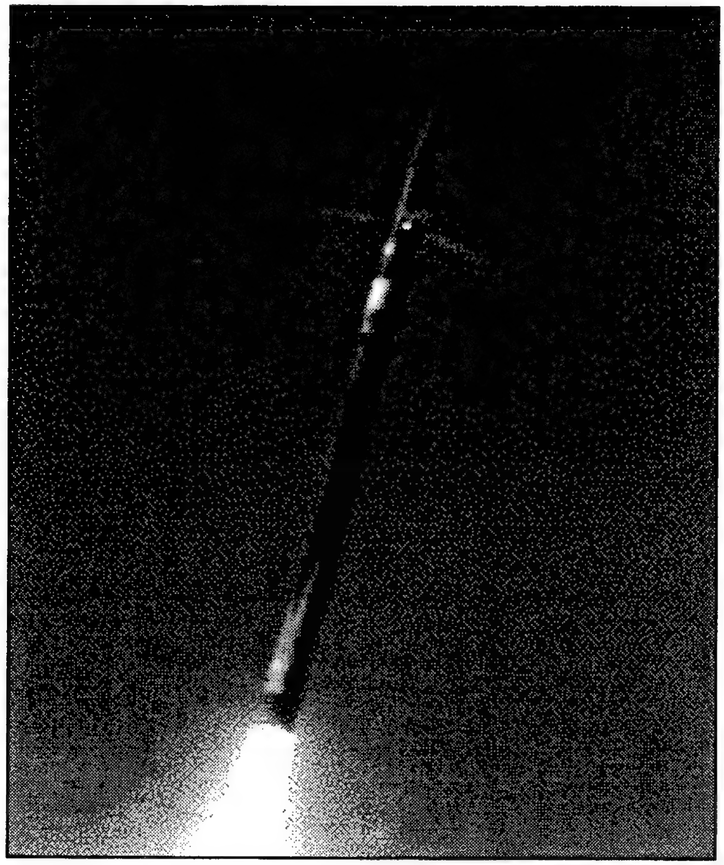

Figure 7. THAAD Flight Test Vehicle Three, From Ref. [16]

The propulsion system consists of a single stage solid propellant booster, a thrust vector control (TVC) system, and deployable aerodynamic flares. The booster's function is to deliver its kill vehicle at desired speed and to required altitude for intercept of the targeted threat. During boost phase, the TVC system steers its missile; this steering action is detectable in Figure 7 near the top of the missile. The booster's aerodynamic flares deploy shortly after launch to provide stability during flight. [Ref. 18]

A KV is the only portion that actually intercepts a targeted TBM. It is a software intensive component that can acquire, lock-on, and then steer itself to intercept. All of these actions occur in a time frame that may last from seconds to less than four minutes.

Together the KV and its target have a combined velocity several times the speed of sound. The KV, which is approximately the front 22 inches of the THAAD missile, uses only the kinetic energy of the high speed impact to destroy its target. [Ref. 16]

A two piece shroud covers the forecone during endoatmospheric flight. This shroud reduces aerodynamic drag and protects the seeker window from aerodynamic heat produced by the KV's high speed flight. Two notable KV features are a gimbal-mounted infrared (IR) seeker and a Divert and Attitude Control System (DACS). The IR seeker "looks" through a rectangular uncooled sapphire window that serves as the KV's "eyes," while the DACS enables the KV to steer itself to point of intercept. All of these complex tasks are possible because of an Integrated Avionics Package (IAP) that uses four reduced instruction-set computing (RISC) computers, which provide the computational speed required for hit-to-kill guidance. [Ref. 19: p. 44]

3. Theater Missile Defense Ground Based Radar

THAAD uses a state-of-the-art X-band phased array radar that performs multiple functions. These functions include surveillance, acquisition, tracking and classification, as well as impact point prediction. The TMD-GBR senses an incoming threat and provides this information to the BM/C3I element to identify the threat and prioritize multiple threats. In addition to tracking threat targets, the radar must also track its own in-flight interceptors and provide in-flight target updates which aid the interceptor in target homing. A kill assessment follows this sequence of tasks. This assessment aids in determination of the need for a second THAAD launch or for cueing to a lower-tier system. Figure 8 shows the radar antenna, cooling equipment unit, electronics equipment

unit, and operator control unit. Not shown is the prime power unit, which is similar in size to the cooling equipment unit.

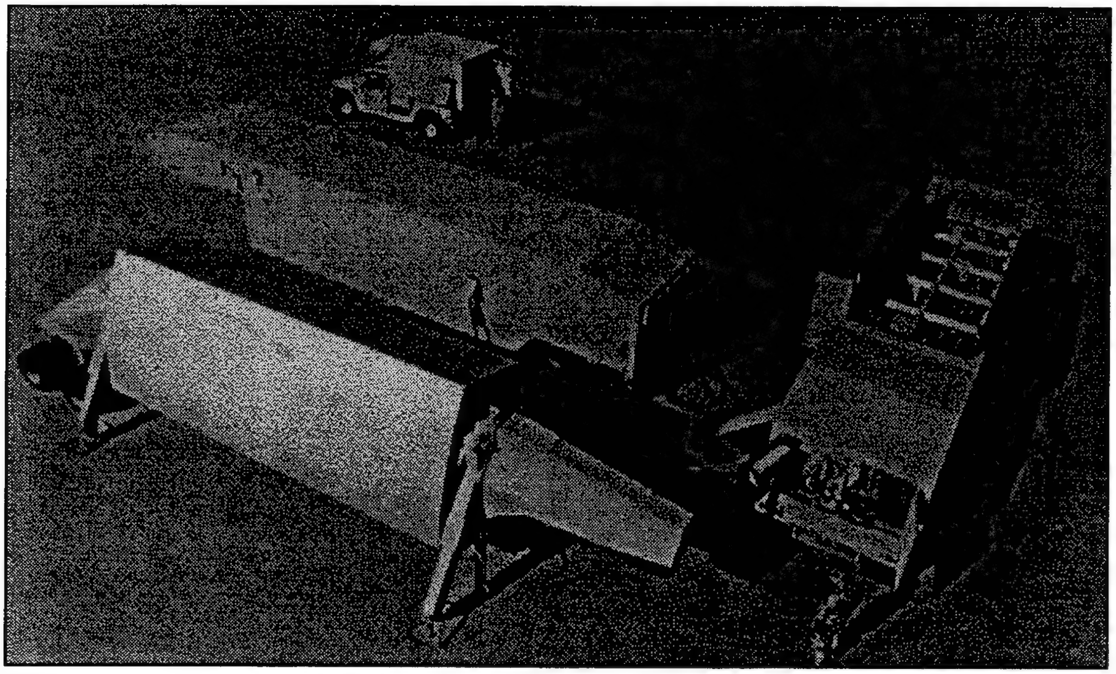

Figure 8. THAAD Ground Based Radar and Support Equipment, From Ref. [16]

4. Battle Management

The BM/C3I subsystem is the integrating component of the THAAD weapon system, and it provides the interfaces to external systems for Joint Operations. THAAD's BM/C3I units (Figure 9) are mounted on standard High Mobility Multi-purpose Wheeled Vehicles (HMMWV). The BM/C3I element uses a Standard Integrated Command Post System (SICPS) to provide crew and equipment protection from extreme environmental conditions. Communications systems include: the Joint Tactical Information Distribution System (JTIDS) for inter-service operations; the Single-Channel Ground and Airborne Radio System (SINCGARS) for internal command and support requirements; and the Global Positioning System (GPS) for rapid and accurate emplacement. The units

Figure 9. THAAD BM/C3I Shelters, From Ref. [16]

come in two configurations, which are the Tactical Operations Station and the Launcher Control Station. Either configuration may provide workstations for force operations such as planning, analysis, and logistic support, or it may provide workstations for engagement operations such as surveillance and battle management. A Launcher Control Station provides direct communication links for the TOC, or it may serve as a communication relay to remote launchers or external sensors when a relay is necessary.

D. COMPARISON OF UOES TO THE OBJECTIVE SYSTEM

Table 3 is an unclassified summary of the cost, schedule, and performance of UOES and the objective system. There have been numerous considerations to increase or decrease the scope of either product. THAAD's large budget attracts much attention from the many other contenders for DOD procurement dollars; consequently TPO has had to conduct several studies to determine the feasibility of combining some of each product's features in an effort to find ways to save money.

MANAGEMENT METRIC	UOES (Including DEM/VAL)	OBJECTIVE SYSTEM (EMD through Full Fielding)
COST (Dollars in millions)	DEM/VAL with UOES Option: $833.8 5 Years of Maintenance: $90.0 Total 5 Year Cost: $923.8 (Maintenance added to EMD Contract)	Development, Operations & Support Over 20 Year Period: THAAD: $9,096.4 TMD-GBR: $5,384.4 Total 20 Year Cost: $14,480.8
SCHEDULE	Delivered by end of Fiscal Year: 1996 Use No Longer Than Fiscal Year: 2001	First Unit Equipped: 2001 (4th QTR) Initial Operational Capability: 2002 (1st QTR)
PERFORMANCE		
Quantity Delivered:		
• **Missiles**	40	1,313
• **Launchers**	4	80
• **Radars**	2	14
Features:		
• Interoperability	• Joint Service interoperability on NON-TMD optimized data link (TADIL-B) with USAF CRC	• Theater wide interoperability on optimized TMD data link (TADIL-J, JTIDS) approximately FY 97
• Remote Source Data	• Utilization of current remote source data Tactical Information Broadcast System	• Maximized utilization of future remote source data from direct or ABM compliant sources
• System Operator Interface	• Computer aided operator generated planning for THAAD battery	• Operator aided computer generated defense planning for a THAAD battalion in theater wide missions
• Netted & Distributed Architecture	• Battery netted and distributed architecture for limited flexibility in THAAD reallocation of sensor, launcher and TOC configurations	• Multiple fire unit netted and distributed architecture for maximum flexibility in near real time allocation of THAAD sensor, launcher, and TOC configurations
• Autonomous Navigation	• Uses GBR to improve pre-launch alignment errors and provide inflate updates	• Uses improved Az Alignment and external (GPS) updates for flyout autonomy with GBR as backup
• DACS	• Additional divert margin desired • Liquid fuels; Toxicity issues; Not low temp OK'd	• Increased divert margin • Gel & solid fuels; Reduced hazardous material; • Increased environmental endurance
Radar Features		
• Aperture	• $9.2M^2$	• $10.2M^2$
• # T/R Modules	• 25,344	• 30,464
• # of Subsystems	• 5	• 4
• Bandwidth	• Baseline	• Twice the baseline
• Sensitivity	• Baseline	• Improved Sensitivity, +100KM detection range

Table 3. Summary of Cost, Schedule, & Performance Trade-off Between UOES & Objective SYS After Ref. [18 & 40]

IV. SUMMARY OF THAAD'S ACQUISITION STRATEGY

A. PURPOSE

THAAD's schedule is widely recognized as aggressive. This chapter describes the key features of THAAD's MS I acquisition strategy and how its features were designed to handle the risks perceived.

Risk management terms used in THAAD's 1992 acquisition strategy vary slightly from the terms described in Chapter II. DOD risk management terminology often varies from program to program. Appendix B relates DSMC's risk management terms to terms used in THAAD's acquisition strategy.

B. PRE-MILESTONE I ACTIVITIES

1. Late 1980s

A September 1988 Ballistic Missile Defense Organization (BMDO) memorandum to U.S. Army Strategic Defense Command (SDC) was a statement of need that requested the most expeditious approach to develop a THAAD missile. At that time, BMDO envisioned THAAD as a new missile only, rather than an entire system. BMDO encouraged leveraging off past missile defense successes by "building on the results of the High Endoatmospheric Defense Interceptor (HEDI)...and the Kinetic Kill Vehicle Integrated Technology Experiment (KITE)." These experiments had proven the hit-to-kill concept and made significant advancements in infrared seekers, active window cooling, and forebody cooling. These were the same technologies a THAAD missile would likely use. [Ref. 20: p. 2]

The U.S. Army Air Defense Artillery School was the user representative, and it worked closely with BMDO to establish performance requirements in the Operational Requirements Document (ORD). BMDO suggested that THAAD should "overlay" existing and future PATRIOT enhancements; later this grew into the upper and lower tier operational requirement. BMDO also envisioned a significant growth potential for interoperability and battlefield information sharing. The THAAD missile would be required to "interface with existing and projected radars, launchers, and BM/C3I networks." [Ref. 20: p. 2]

The Air Defense School was a strong proponent for significant user participation in development of the THAAD missile. Regional commanders were demanding better TBM protection. Earlier in the 1980s, PATRIOT's PM had experienced major problems with initial operational testing. Those problems came from lack of user input into the operations and maintenance concepts. As a result, it required a total of six operational tests to field PATRIOT. With THAAD, the Air Defense School insisted on greater participation. [Ref. 21]

2. Early 1990s

In September 1990, shortly after deployments to Operation Desert Shield began, a second BMDO letter re-affirmed the urgent need for THAAD. This letter formally initiated the program's Concept Definition (CD) phase. BMDO also enlarged THAAD's scope to develop a complete weapon system rather than a missile only. By January 1991 BMDO accelerated THAAD's schedule and called for a demonstration system to be

capable of emergency deployment in 1995. The legislative mandate for an operational capability was expressed in the Missile Defense Act of 1991. [Ref. 20: p. 2]

THAAD's increased scope and its schedule acceleration were a direct result of world events. Between 1988 and 1991 the Soviet Union had collapsed, and the emphasis of U.S. National Military Strategy began to shift toward rapid force projection. This required greater flexibility in terms of transportability. The only defensive system, PATRIOT, was air transportable, but it required far more C-5 aircraft than were readily available. Furthermore, Operation Desert Storm highlighted PATRIOT's limited TBM defensive capability. The increased visibility of the growing ballistic missile threat justified the schedule acceleration and the enlarged size of the program. [Ref. 21]

Three contractor teams participated in CD starting in August 1990. The initial objectives of this phase were for competing contractor teams to:

- Define technologies and system concepts required for the development of a cost effective system; this would help control technical and cost risks.
- Conduct system trade studies to optimize design compared to schedule, technical, and cost risks.
- Specify plans to develop and demonstrate high risk technologies; this would help identify the most appropriate plan, given high schedule risk.

In December 1991 the competitors delivered their system specifications (Type A) for their missile, launcher, and BM/C3I element designs. Due to THAAD's aggressive schedule, TPO also requested the teams' design specifications (Type B) for their missile and launcher. (B SPECS are usually not delivered until DEM/VAL [Ref. 22: p. 1.1-3].) They also delivered their recommendations based on their trade studies and their plans to demonstrate high risk technologies.

BMDO staffed the ORD through the Joint Requirements Oversight Counsel to the USD(A&T). The MS I decision came on 28 January 1992 when the USD(A&T) approved THAAD's Acquisition Decision Memorandum (ADM). [Ref. 23: p. C-4]

C. MILESTONE I ACQUISITION STRATEGY FOR DEVELOPMENT

1. Expanded CD Phase Objectives

As a result of the program's acceleration and increased scope, the THAAD Project Office extended the CD phase from December 1991 until May 1992 to perform additional risk handling or "risk mitigation" activities. During this extension, the contractor teams developed their:

- Software interface requirements and specifications.
- Software requirements specifications.
- Software development plans. [Ref. 23: p. C-4]

2. Demonstration and Validation

Traditionally the purpose of this phase is to demonstrate critical processes and technologies. This goal is often accomplished with very limited prototypes that focus on high risk components. As part of MS I risk planning, TPO established DEM/VAL objectives that went far beyond the traditional approach. BMDO's objectives for this phase were to further develop and integrate technologies into an operational prototype, or UOES, that would have a useful TMD capability.

The MS I strategy called for the UOES package to include four launchers, four BM/C3I units, two TMD-GBR radars, and 40 UOES missiles. The prime contractor would deliver the launchers and BM/C3I units under the DEM/VAL contract. As a technical and supportability risk control measure, TPO placed the 40 UOES missiles in a

separate contract option. The strategy called for exercise of that option once the system demonstrated a useful military operational capability. This arrangement would help TPO avoid the risk of premature commitment to an immature design.

Exit criteria for DEM/VAL phase included requirements that the contractor demonstrate, through flight test and simulation, the design's ability to:

- Achieve target acquisition.
- Complete BM/C3I functions.
- Achieve missile burnout velocity.
- Conduct in-flight maneuvers in response to GBR updates.
- Conduct KV terminal homing, or "end game" divert maneuver.
- Perform hit-to-kill intercept.
- Conduct kill assessment.

The strategy established UOES contract option acceptance criteria, which are:

- Successful hardware-in-the-loop (HWIL) demonstrations of guidance and control systems.
- One guided flight to intercept of a target using a TMD-GBR.

UOES acceptance criteria were a subset of DEM/VAL exit criteria. The strategy called for a 48 month DEM/VAL phase, which TPO planned to last from fourth quarter fiscal year (FY) 1992 until fourth quarter FY 1996. MS I estimates called for exercise of the UOES option in the fourth quarter FY 1995. [Ref. 23: p. C-5]

To control technical and schedule risk, the strategy emphasized an event driven program rather than a schedule driven program. The event driven feature of the strategy would help control technical risk by not rushing through the design and interface processes just to satisfy the legislative mandate. The event driven feature would also help control schedule and cost risks by allowing the flexibility to accomplish some tasks before they were scheduled, if that would reduce overall risk. [Ref. 18]

3. Engineering & Manufacturing Development

The MS I acquisition strategy allocated 30 months for EMD. This upcoming phase is currently scheduled for October 1998 through March 2001. The focus of THAAD's EMD is to refine system design, to validate a producible design, and to validate that the design is fully supportable within the existing Army logistics structure. During EMD, an operationally deployable THAAD battery will "own" the UOES interim prototype. The experience in use and testing of UOES equipment will be a valuable source of user feedback to enhance the objective system's suitability. The objective system will differ from UOES because it will incorporate design changes resulting from UOES and EMD testing. EMD objectives include:

- Full qualification of all system components.
- Integrated Logistics Support Plan (ILSP) completion.
- Material Fielding Plan (MFP) completion.
- Functional and physical configuration audits.
- Environmental testing.
- Threat requirements and available technology update. [Ref. 23: p. C-5]

4. Risk Management Structure

The MS I acquisition strategy reflected several coordinated and ongoing risk planning activities. Risk management for DEM/VAL built upon the objectives that contractors had met during CD and its five month extension. A risk assessment identified the watchlist areas that would be the most critical to the program's success.

Table 2 is the author's summary of all the key risk management issues addressed in the MS I acquisition strategy.

Facet of Risk and Watchlist Area	Overall Risk Assessment	Risk Handling Techniques
<u>Technical</u>	**Moderate**	
• Radome heating		• *Avoid & control* by using design based on existing technology or technology already in development
• High altitude engagement		• *Avoid & control* by maximum use of commercial-off-the-shelf items and common hardware and software
• System integration		• *Control* by encouraging prime contractor team with subcontract specialists
• Seeker technology		• *Control* by dual sourcing IR seeker and parallel development of critical components
<u>Supportability</u>	**Low**	
• Interoperability		• *Avoid & control* by requiring interface with existing and projected systems
• Integrated Logistics Support (ILS)		• *Assume* by having contractor support UOES and deferring some supportability issues until EMD
• Weight & Size		• *Avoid* by requiring C-130/C-141 transport
<u>Cost</u>	**Moderate to High**	
• BM/C3I Software		• *Control* by design based on existing technology or technology already in development
• KV Avionics Package		• *Control* by Monthly Cost Performance Reports and Quarterly Risk Assessment Reports & Performance Reviews
<u>Schedule</u>	**High**	

• Complete resolution of engineering & integration issues by 4th QTR 95		• *Assume & control* by developing an operational, deployable prototype at the end of DEM/VAL
		• *Partially avoid* by reducing environmental requirements until objective system
		• *Partially avoid* for UOES by having contractor provide all maintenance
		• *Control* by Contract requirements for
		  • Monthly Cost Performance Reports
		  • Quarterly Risk Assessment Report

• GBR		• *Transfer* by having NMD develop the radar and provide a TMD version as Government Furnished Equipment

Table 4. The Author's Summary of THAAD's MS I Risk Management Structure

TPO's initial risk analysis found that Integrated Logistics Support (ILS) was a low risk area for DEM/VAL (although TPO assessed that it would become a critical risk area during EMD). The strategy required that the contractor establish an ILS Plan (ILSP) during DEM/VAL, but it did not require a finalized ILSP until MS III. To avoid additional schedule risk, TPO determined it would be more cost effective to have the contractor provide all maintenance for the UOES during its planned five year life-cycle. The objective system is envisioned to use a three-level maintenance concept. The system will be fully maintainable at the unit by military personnel and will require contractor support for intermediate and depot maintenance. [Ref. 20: p. 10]

5. Competition And Contracting

Before gaining approval for its acquisition strategy, TPO considered several other alternatives. To evaluate alternatives, it was essential to separate near and long term program objectives. In the long term, TPO was required to deploy a complete tactical system as soon as feasible at affordable cost and acceptable risk. In the near term, by law, TPO had to complete DEM/VAL as quickly as possible with an operational prototype. This requirement was far beyond traditional MS II decision requirements; it meant TPO must resolve operational issues much earlier than in the traditional acquisition approach.

One alternative was competitive prototyping. TPO requested exemption from the competitive prototype alternative as required by DOD policy. Estimates indicated carrying two contractors through DEM/VAL could add approximately $1.2 billion to program cost. Furthermore, duplicate testing would increase schedule risk. These

additional cost and schedule risks would result in a net risk increase under a competitive prototype strategy. [Ref. 23: p. C-14].

Another alternative called for two system integration contractors to develop paper designs or very limited component prototypes during a 12 month period. These designs would have focused on high risk components, and at the end of the period the contractors would have submitted the designs for a competitive selection. TPO rejected this alternative because it increased technical risk. For THAAD, paper designs could not answer the critical questions:

- Would the concept be feasible?
- Would the design work the way it was supposed to work?
- Will the system provide a useful military capability?
- Will the system meet the performance requirement?

TPO recommended "single source with risk mitigation" as the best alternative course of action. At the MS I decision TPO gained approval to competitively select a single THAAD system contractor for DEM/VAL, and that contractor would have sole source responsibility for all remaining phases. To control a myriad of risks associated with a single source development and production contract, TPO would fund the contractor to conduct a risk reduction program, which included implementation of a risk mitigation plan. This plan would include dual sourcing the IR seeker, parallel development of critical components, and requiring the prime contractor to maximize competition at the subcontract level.

The acquisition strategy recommended a cost-plus-fixed-fee (CPFF) contract for DEM/VAL because of technical and cost risks associated with integrating a variety of

leading-edge technologies. For EMD, the strategy recommends a cost-plus-incentive-fee (CPIF). When THAAD reaches Production and Deployment, the strategy recommends a firm-fixed-price contract. [Ref. 23: p. C-15]

The basic DEM/VAL contract includes development of four launchers, two BM/C3I units, 20 flight test missiles, and the software required to achieve exit criteria. The prime contractor will deliver each of these items whether or not the PM exercises the UOES contract option. Not included were the GBRs, which were to be provided as GFE. (Radar development was part of a $492.2 million NMD contract that included development of a TMD version of the GBR). [Ref. 24: p. 7]

TPO used full and open competition to award the DEM/VAL contract. A synopsis appeared in the Commerce Business Daily on 10 June 1991 announcing a draft request for proposal (RFP). The draft proposals that were received were used in writing a more definitive final RFP. The final RFP went out on 30 January 1992. The Source Selection Evaluation Board (SSEB) evaluated three contractor teams' proposals and reported its findings to the Source Selection Advisory Council (SSAC). The SSAC's recommendation went to the Secretary of the Army, the Source Selection Authority (SSA).

On 4 September 1992 Lockheed Missiles and Space Company (LMSC), subsequently renamed Lockheed Martin Missiles and Space Company, won the contract. LMSC is now the prime contractor for the DEM/VAL, EMD, and Production and Support phases. The contract has an estimated cost of $695.9 million with a fixed-fee of $57.8 million, or 8.3% [Ref. 25: p. 1].

The UOES contract option is for 40 contingency capability missiles and the contractor's maintenance support through the five-year expected life of the UOES. Estimated cost for the missiles is $73.9 million with a fixed-fee of $6.2 million. The five years of complete contractor support, estimated to cost up to $90.0 million, will be included in the EMD contract. [Ref. 25: p. 12]

6. Funding the Contingency Reserve Missiles

Funding for the UOES option has been a complex legal issue that has required careful management. On one hand, there is a specific legislative mandate that required an operationally effective TMD capability by 1996. On the other hand, DOD Regulation 7000.14-R places legal restrictions against using Research, Development, Test and Evaluation (RDT&E) funds to procure purely operational equipment [Ref. 41: p. 5]. The appropriated funds required for the basic DEM/VAL contract and the TMD-GBR are easily classified as RDT&E funds, but funds for the 40 missiles in the UOES option are not as easily classified. By definition the UOES missiles can not be expended during developmental testing because they must be available for contingency deployment. BMDO has addressed this issue by emphasizing the three prioritized purposes for the UOES. "The UOES will be used for early operational assessment and for soldiers to influence the final design, but will also be available for use as a contingency capability during a national emergency [Ref. 26: p. A-19]." Furthermore, BMDO has recommended exemption to the restriction to allow the 40 missiles to be kept in contingency reserve and not used for EMD testing. [Ref. 41: p. 12]

D. CHAPTER SUMMARY

The innovation found in THAAD's acquisition strategy is its commitment to exit DEM/VAL with an operational prototype. This chapter presented the features of how TPO tailored the MS I strategy to address the program's risks. To help handle high risk technologies, TPO built the strategy upon advancements made in missile defense experiments in the 1980s. To handle the risks brought on by an aggressive schedule, TPO extended CD and imposed more stringent exit criteria for each phase. Since competitive prototyping would take too long and cost significantly more money, TPO was able to gain approval for a competitive award to one system contractor for DEM/VAL and all remaining phases. To handle the risks associated with single source procurement, TPO funded the prime contractor to dual source some critical items, develop others in parallel, and maximize competition at the subcontractor level.

V. IMPACT OF THE STRATEGY AND LESSONS-LEARNED

A. PURPOSE

The ultimate evaluation of the effectiveness of THAAD's acquisition strategy will take place when the system first faces an incoming threat. The final chapter on THAAD may not be written for many years; however, based on early results, an interim assessment is possible. This chapter is the author's observations of the tailored acquisition strategy's impact on key program risks. It begins by citing some examples of what has occurred in the THAAD UOES program as a result of the TPO's tailoring of the acquisition strategy to manage key risks. From these observations the chapter develops acquisition management lessons-learned.

B. OBSERVED IMPACTS OF THE STRATEGY

1. System-Wide Initiatives

a. Commonality

LMSC responded to TPO's stated preference for commercial-off-the-shelf (COTS) items by incorporating existing DOD equipment wherever possible. Visible examples of common items are the PLS, the HMMWV, and the SICPS. Examples that are less noticeable include THAAD's generators, computers, JTIDS and SINCGARS radios, and GPS receivers. LMSC's use of these common components avoids some technical risk because these subsystems are already operational. They avoid supportability risk because they have established training and logistics infrastructure. For these items, there is practically no cost and schedule risk because LMSC can order them

from the vendor for an established catalog price. Use of common items helps focus the development to those items that do not yet exist. With this more accurate view of the scope of the program, the programmatic decisions can be confined to the truly new components.

Use of common items presents some increased technical risk. These items were not specifically designed to perform a TMD function; consequently, THAAD's design engineers have to work within the limitations of the common items. In the design process there is a trade-off of performance (some technical risk is assumed) to gain a decrease in cost, schedule, and supportability risks. THAAD's designers assessed that the performance objectives could still be achieved while using many common inventory items. This trade-off resulted in an overall risk reduction for the program.

b. System Integration Laboratory

System integration is a watchlist item that TPO assessed as a moderate risk at MS I. LMSC, prime contractor for a team of more than 45 specialty subcontractors, concurred with this assessment. In response to TPO's requirement for a risk mitigation plan, LMSC developed its System Integration Laboratory (SIL) and Missile Simulation Laboratory. These two facilities are prime examples of LMSC's exploitation of state-of-the-art prototyping methods to control technical risks associated with interfacing existing hardware and software with new hardware and software.

"The SIL provides a high fidelity test lab to verify THAAD subsystem and system performance in a realistic and programmable combat environment [Ref. 16]." LMSC and many of its subcontractors use rapid component prototyping to produce a

design. That design then undergoes hardware-in-the-loop testing, which allows a variety of testing configurations. The physical or the digital product may be combined with a prototype of new or revised software modules to test the impact of design modifications in a virtual or semi-virtual environment. The SIL facilitates integration of all weapon system hardware and software elements.

"The Missile Simulation Laboratory provides the high fidelity simulated flight environment necessary for dynamic testing of missile segment components from launch through intercept [Ref. 16]." This lab permits real-time virtual operation of the KV's integrated avionics package. These operations are conducted in a simulated flight environment that closely approximates an actual in-flight environment. The Missile Simulation Lab provides a means to develop, test, verify, and validate software algorithms used by an in-flight missile and its KV.

The SIL and Missile Simulation Lab are valuable prototyping facilities that enable LMSC and its large team of subcontractors to efficiently refine a component's design and its interfaces with minimal schedule and cost risk. These facilities allow LMSC to conduct almost continuous testing of every hardware and software component in every configuration with much less cost and schedule impact than full scale testing.

These labs enhance the value of data collected during full scale testing. When flight test three did not meet all of its test objectives, LMSC was able to "replay" the flight test data in the lab. This enabled software and design engineers to trace the performance deficiency to its root cause, thereby helping to control technical risks.

2. Impact on Subsystems

a. Interceptor

As part of its risk control activities, TPO funded numerous preflight tests on various missile components before start of full scale flight testing. The objective of these preflight tests was to control technical, cost, and schedule risks by verifying a component's compatibility and functionality without incurring costs associated with actual flight. Preflight tests began during CD and still take place after each significant hardware or software change. Several static firings validated the booster's solid propellant design and the TVC system's ability to steer the missile during boost phase. A series of "simulated hot launch tests" provided missile launch verification and demonstrated proper aerodynamic flare deployment. LMSC verified the DACS's ability to steer its KV in a typical flight scenario through hardware-in-the-loop testing with all interceptor subsystems on-line. [Ref. 16]

Once LMSC verifies a component's compatibility and functionality, it is integrated into a complete missile for actual flight testing at White Sands Missile Range. Original DEM/VAL objectives called for 20 flight tests. The flight tests started with simple test objectives. Each subsequent test builds on previous lessons-learned and demonstrates revised versions of software and hardware as they mature.

To control high schedule risk, the PM obtained Milestone Decision Authority permission to reduce flight tests to 14 because of early testing success. The original preflight and the flight test programs allowed for some re-testing, if necessary, with redundant test objectives. Once LMSC met those test objectives the PM

recommended restructuring the flight test program to eliminate unnecessary testing. The PM's recommendation was a trade-off to assume some moderate technical risk in order to lower the program's high schedule risk.

Hit-to-kill technology currently borders between state-of-the-art and cutting-edge. LMSC is avoiding some technical risks by building THAAD based on experience in the HEDI and KITE experiments, as well as other missile defense demonstrations. Designing THAAD's KV is technically feasible because engineers are essentially repackaging existing hit-to-kill technology rather than completely developing new technology [Ref. 15].

Production of KV components is a leading example of LMSC's use of rapid prototyping to control technical, cost, and schedule risks. The producibility plan emphasizes close interaction among all engineering disciplines. From the start of conceptual design, producibility engineers have continuous access to the designers' database. This allows for producibility analysis concurrent with system design. When a producibility problem arises, design engineers take corrective action before they waste resources on a faulty design. For example, in production of some forecone parts, there was a paperless transfer of the design to numerically controlled machining tools. The subcontractor for the shroud that covers the interstage between booster and KV also used rapid prototyping to design and integrate this critical component. [Ref. 16]

The interceptor is the subsystem that has the highest technical risk. Schedule pressure increased this risk by forcing reliance on a single contractor for DEM/VAL and all remaining phases. To control this risk TPO emphasized teaming

arrangements between LMSC and subcontract specialists. The SIL and the Missile Simulation lab are LMSC's response to the need for an efficient method to integrate the various specialists' components to produce the best overall technical system. Considering early flight test success, this approach of integrating teams of specialists has helped to control technical risks. This reduction in interceptor technical risk also reduces the cost and schedule indicators of risk.

b. Ground Based Radar

Major risks for the GBR lie in its extensive use of software. TMD-GBR is reusing about 300,000 lines of missile defense-related software code [Ref. 27: p. 50]. BMDO and Advanced Research Projects Agency (ARPA) developed this reusable code during previous missile defense experiments. This code is a starting point for the GBR prime contractor, Raytheon, to develop a series of evolutionary software prototype builds. Raytheon works with LMSC in the SIL to integrate these software prototypes with the other subsystems before flight testing. After a flight test the contractors continue to refine the software prototype based on its effectiveness to meet that flight test objective. Software reuse and evolutionary software prototyping techniques have helped control technical, cost, and schedule risks. [Ref. 28: p. 4-7]

GBR's 1992 operational requirement called for a complete radar set to be transportable on five C-130s. [This requirement imposed a size and weight limitation which drove the use of solid-state transmit and receive (T/R) modules in the antenna.] Each of three DEM/VAL radar antennas contains 25,344 solid-state T/R modules, and each module contains nine monolithic microwave integrated circuit chips (MMIC). The

technology used in the T/R modules was not itself a breakthrough; however, assembly of over 75,000 miniature modules in less than two years was a high technical risk. To control this risk, GBR's acquisition strategy required the prime contractor to dual source certain high risk components. Raytheon produced some of the T/R modules and subcontracted out the remaining portion. To control risk, the PM closely monitored production of T/R modules on a monthly basis. [Ref. 29: p. 504]

c. BM/C3I

The BM/C3I element, like the KV and GBR, is a software intensive subsystem, BM/C3I software differs because of its high degree of human interface. Software for the KV is best designed with input from physicists, but software for the BM/C3I is best designed with input from soldier operators. The subcontractor for the BM/C3I element is Litton Industries, and to date it has delivered four operational BM/C3I shelters. Two units are used to support DEM/VAL flight testing at White Sands Missile Range. Two more units are used to verify hardware and software interfaces in the SIL. Soldiers assigned to the first THAAD battery have almost daily access to the systems and are currently helping design engineers evaluate BM/C3I operator system interfaces. Their valuable input is part of a growing human factors study that will help to refine suitability of THAAD's software and hardware. [Ref. 21]

Recent LMSC risk assessment reports list software as having high technical, cost, and schedule risks. To control these risks Litton also relies on evolutionary software prototyping techniques. Current plans call for seven major incremental software builds to achieve full functionality in the objective system. The

UOES version will use the third major build, which designers expect will contain 372,000 lines of Ada code. This is about half of what the objective system will require [Ref. 27: p. 50]. To control schedule risk, TPO has at times removed or deferred some functions from incremental software builds.

Litton controls hardware technical and supportability risks by closely monitoring throughput and memory utilization. To control high schedule risk for UOES development, TPO made some risk trade-offs in areas of the program that would require more time to resolve than was available. For example, TPO was able to gain a waiver for the requirement for electromagnetic pulse (EMP) hardening of the system. LMSC is required to resolve these issues as part of a larger "Growth to Objective System" plan. LMSC and Litton are conducting ongoing trade studies to define the optimum hardware design for the objective system. [Ref. 15]

Many external interface requirements stem from BMDO's goal to coordinate all missile defense BM/C3I issues. This goal has increased technical and programmatic risks for THAAD. For example, the JTIDS radio is an externally driven hardware requirement. This radio lacks adequate throughput for THAAD to mature to full objective system capability. TPO projects that the objective system will need communications throughput capability of one megabit of information in half a second or less. TPO is currently staffing a request to replace JTIDS with the Secure Packet Radio (SPR) because it is the only radio on the market that can provide adequate throughput capability. [Ref. 30]

3. Programmatic Risk

Programmatic risk has fluctuated widely, primarily as a function of political support and perceived threat. Since January 1992, when THAAD's acquisition strategy was formally approved, there have been some significant external events that have affected the program. These external events center around three interrelated issues: (1) the diplomatic regulation of some of the THAAD system's features under the Anti-Ballistic Missile Treaty, (2) the political maneuvering around the definition of the ballistic missile threat, and (3) the Federal Budget crisis. These three issues have resulted in much more scrutiny of the THAAD program than was expected back in 1990 and 1991 when the UOES approach was adopted.

There are clear political lines drawn over the validity of the Anti-Ballistic Missile Treaty. One side of this issue stresses that the Soviet Union no longer exists and the United States missile defense programs, including THAAD, should not be constrained by an outdated agreement. This side of the argument also emphasizes that the talented personnel that built the former Soviet Union's ballistic missile arsenal have dispersed to many rogue nations around the world. The other side of this issue stresses that much of the former Soviet Union's nuclear arsenal still exists and so the Anti-Ballistic Missile Treaty should remain in effect, constraining THAAD development. Under this thinking, the most effective method to reduce the threat is through diligent diplomatic negotiations with the new nations who possess remnants of the Soviet arsenal.

As mentioned in Chapter I, the Clinton administration has downgraded the NMD program to a Technology Readiness Program. Until June 1995, the GBR was a separate

NMD project office that would provide the THAAD program with two radars as GFE. This was a practical approach given the similar functions and design shared between the TMD and the NMD versions of the radar. In 1994 when the Clinton Administration downgraded NMD to a Technology Readiness Program, TPO began to assume most of the $492.2 million responsibility for development of its own radar [Ref. 31: p. 89]. Since June 1995, GBR has been a product office within the TPO.

This project office merger was a programmatic risk for the program in that it meant increased development responsibility for TPO. GBR was also in DEM/VAL, but its acquisition strategy called for a competitive selection for the EMD contract. Raytheon was not under contract to develop an objective system; its focus was only to deliver three DEM/VAL operational prototypes, which would consist of one NMD version and two TMD versions. TPO had to modify Raytheon's contract to include concurrent work on an objective system. For the remainder of DEM/VAL Raytheon and LMSC have an associate contract relationship. This new arrangement required the two contractors to exchange technical information, as needed, based on an information exchange agreement.

There are political lines drawn around the issue of ballistic missile threat. One side of the debate emphasizes the intelligence assessments that a threat to the United States already exists, or it will exist in less than five years. The other side of the debate emphasizes that some intelligence estimates indicate that a ballistic missile threat is not a significant concern for 15 or more years. This continuing debate creates uncertainties about the future of the THAAD's objective system.

Programmatic risks, as evidenced by changing policy, continue to be high. For example, from November 1995 until February 1996 DOD conducted a complete review of all missile defense programs. In mid-November PEO for Missile Defense recommended a two year acceleration of the objective system [Ref. 32: p. 4]. By early January this proposal became known as the "THAAD lite," which would be a reduced capability objective system [Ref. 33: p. 3]. However, the SEC DEF had a news conference on February 16, 1996 to announce changes as a result of the missile defense review. The result was significantly different from the PEO's recommendation. In that conference the SEC DEF announced:

- The objective system will lose about $2 billion out of what was a $5 billion program through the future years defense plan (FYDP).
- The objective system will be delayed.
- The UOES will be enhanced with some seeker and radar improvements.
- In two years, after Navy Upper-Tier completes CD phase, it will consider a marinized version of THAAD's missile to use on the Aegis missile defense platform. [Ref. 34: p. 6]

All of this political and diplomatic maneuvering leads to high programmatic risk for UOES and the objective system. In the short term, for UOES, the additional development responsibility increased technical, supportability, schedule, and costs risks. In the long term, development and delivery of the full objective system is at risk. Early successes within the UOES portion of the program fostered a perception that perhaps some of the funding for the objective system was unnecessary or that it could be deferred with little consequence. Programmatic risks are inherently unpredictable, and many of THAAD's other types of risk are traceable to external requirements that are beyond TPO's span of control.

4. Cost And Schedule Growth

As typical of most programs, THAAD has experienced both cost and schedule growth. Chapter II indicated some expected cost and schedule outcomes for programs that make extensive use of prototypes (Figures 3 and 4 as well as Table 2).

As of March 1996, the DEM/VAL contract estimate at completion is approximately $1.2 billion (this figure includes the UOES option and the five years of maintenance that will be added to the EMD contract)[Ref. 35]. The program is primarily event driven, but it is about 12 months behind the original schedule [Ref. 35]. It is still too early in the program and beyond the scope of this thesis to determine exactly what portion of the cost and schedule growth is attributable to what types of risk. However, based on observation of the contractor's response to the strategy and events that have occurred since MS I, an interim assessment of cost and schedule follows.

The CPFF contract DEM/VAL including the UOES option was based on a total price of $923.8 million. The current estimate at completion is $1.2 billion, so it appears that there is about $276 million in cost growth. However, the largest portion of this cost growth is traceable to the increased scope of work related to development of the GBR. Both the LMSC and Raytheon contracts have thus had major modifications, and resolving these modifications is an ongoing issue. Estimates indicate that the additional cost traceable to GBR will exceed $200 million. Another increased scope of work is related to electromagnetic pulse hardening of the UOES equipment. This additional requirement will add several million dollars to THAAD's development cost. This requirement is a result of recent considerations to use the UOES system longer than its planned five year

life. The UOES equipment does not contain many of the features of the objective system, and therefore additional requirements lead to high supportability and cost risks.

Initial assessments of THAAD's schedule as "aggressive" have proven to be accurate. The twelve month schedule growth is almost solely attributable to software issues among the interceptor, GBR, and BM/C3I elements. The contractors continue to employ teams of specialists in this critical program area and rely on proven methods, but schedule risk is usually very high for complex software [Ref. 36: p. 52].

C. LESSONS-LEARNED

The following list of lessons-learned come from the author's observations of what has occurred thus far in the THAAD program. This list is an overall interim assessment of the acquisition strategy based on events and actions from the first statement of need in 1988 until March 1996.

- **Use of common existing inventory items as subsystems helps avoid some technical risk.** Because those subsystems are already operationally effective and suitable systems, they help avoid supportability risk with an established training and logistics infrastructure. For these items, there is very little cost and schedule risk because the items may be provided as GFE or separately purchased from a vendor. Use of common items helps isolate the scope of the development to those functions that do not yet exist.

- **Use of common existing inventory items can also increase technical risk.** Existing inventory items are, by definition, not specifically designed to perform THAAD's TBM function. Design engineers had to work within limitations of the existing system's capability and assumed some technical risk in a trade-off for lower cost, schedule, and supportability risk.

- **Funding a contractor for a system integration initiative can help maximize the benefits from component, software, and virtual prototyping methods.** This can help control schedule and cost risk through virtual or semi-virtual testing to avoid commitment to a testing program until interface of the hardware and software components can be established. An integration facility can help control technical risk by efficiently optimizing an overall system design. It can increase the value of actual testing by providing the means to conduct in-depth analysis of actual test data to help identify a root cause of a performance deficiency.

- **Software technical risks can be partially controlled by reusing the existing software of systems that have similar functions.** For THAAD, reused software became a starting point for a series of evolutionary software prototype builds, which helped to control technical, schedule, and cost risks.

- **Rapid prototyping, combined with hardware-in-the-loop testing, enables a variety of design configurations with minimal cost and schedule risk.** Use of rapid prototyping methods helped control technical risks by allowing technical designers to communicate their design more efficiently to non-technical audiences. In THAAD, rapid prototyping is credited for helping to control technical and schedule risk by providing for a paperless transfer from design equipment to numerically controlled machining tools.

- **Test objectives should be incremental, allow for integration of revised versions of hardware and software, and take advantage of simulation in testing.** A thorough preflight test program enabled TPO to verify hardware and software components' compatibility and functionality after each significant configuration change and before start of full scale testing. TPO used the preflight test to control technical, schedule, and cost risks. When LMSC accomplished some test objectives early, TPO was able to partially control high schedule risk by assuming moderate technical risk.

- **Reconfiguration and refinement of existing technologies can help to control technical and schedule risks.** Rather than completely developing new technology, TPO required the prime contractor to avoid some technical risks by building THAAD based on proof of concept that occurred in previous missile defense experiments.

- **Programs on very aggressive schedules often have to make concessions in some functional areas to achieve the schedule requirement.** TPO recognized early that there was not sufficient time to establish and refine a logistics support plan for the UOES. Before MS I TPO conceded that the contractor would have to provide this function. To control technical and supportability risks associated with this operational concession, TPO required the prime contractor to develop and maintain a Growth to Objective System plan, which established clear paths of development from UOES to the objective system.

- **If a program must rely on a single source for development and production, the PM should take significant precautionary measures to control the risk associated with sole source procurement.** TPO emphasized teaming arrangements, and LMSC is essentially the program integrator for a team of 45 specialists. To control risk TPO funded LMSC to develop a risk mitigation plan, which includes the SIL and the Missile Simulation Lab. Other precautionary measures included: dual sourcing certain high risk components; developing parallel designs until the best one is identified; and funding trade studies in high risk functions to identify an optimal design.

- **Programmatic risk receives too little consideration during risk management planning.** Strong political support initially gave the legislative mandate that resulted in a UOES operational prototype strategy. Four years later, decreased political support resulted in increased programmatic risk. Now the objective system may not be fielded until much later than originally planned, or the objective system may have much less performance capability than originally planned. The recent DOD-wide missile defense review announcement confirms one of the disadvantages of prototyping in that it delays a full funding commitment. Programmatic risk associated with the NMD program resulted in increased technical, supportability, schedule, and cost risks for UOES. The GBR is now back on track and keeping pace with THAAD's schedule, but in 1994 and 1995 the outcome was uncertain.

VI. CONCLUSION AND RECOMMENDATIONS

A. SUMMARY

This thesis is an early examination of the THAAD program's implementation of the User Operational Evaluation System acquisition strategy. It developed a framework for analysis of UOES risk management issues using DOD risk management guidance. This framework incorporates some current methods, applications, and trends in the roles prototypes play during development. Using that framework, it analyzes the observed impact of THAAD's tailored acquisition strategy on the program thus far. From these observations it listed lessons that have been learned from the program's experience, and the author offers the following general conclusions and recommendations.

B. CONCLUSIONS

- **The User Operational Evaluation System acquisition strategy is a special response to a unique situation.**

An analysis of the situation that resulted in the UOES approach supports this conclusion. The BMDO planners had to tailor an acquisition strategy to meet the 1991 legislative mandate for "an operationally effective TMD capability by 1996." This mandate was a result of a growing political concern for ballistic missile defense at home and for forward deployed U.S. forces. This unique and urgent mandate combined with restrictions imposed by the Anti-Ballistic Missile treaty limited the range of options available. A traditional acquisition strategy could not produce a fieldable system until several years beyond 1996. A UOES approach would be much faster because it would

rapidly develop only core capabilities. The strategy is based on the premise that schedule risk was decreased for UOES because it does not include final plans for logistics, training, and full operational capability of the objective system.

- **An operational prototype strategy shifts much of the technical and supportability risks related to operational requirements forward in the acquisition cycle.**

An example of this is that design specifications were part of the DEM/VAL competitive proposal process. Typically, no more than system specifications are required at the end of CD. This accelerated requirement increased technical and supportability risk by requiring designers to commit to a particular design much earlier in the acquisition cycle than this critical step usually occurs. Another example is that the system has to achieve a limited operational capability before MS II. To partially offset this increased risk, the TPO has required parallel development of some critical components to allow for a ready alternative if the primary design is not technically feasible or supportable. Both of these requirements resulted in increased development schedule and costs.

- **An operational prototype strategy increases programmatic risk by creating an alternative to commitment to full objective system funding.**

This conclusion is consistent with the findings discussed in Chapter II, and for THAAD this conclusion is evident from the programmatic events that have occurred since 1991. BMDO planners did not adequately consider long-term programmatic risk when they adopted the UOES approach. Long-term success hinged on a limited UOES capability to temporarily meet the requirement, while designers would use experience gained from its operation to help develop a more robust objective system. Now, five

years after selection of the UOES approach it appears the UOES is going to be kept longer, and the scope of that portion of the program will be enlarged at the expense of the objective system.

- **DOD's Advanced Concept Technology Demonstration now addresses many of the same objectives that the UOES attempted to achieve.**

Both approaches have overlapping goals in that: (1) user experience gained from operating the system is used to help refine a more suitable final product, (2) if needed, the system is available for a contingency mission.

C. AREAS FOR FURTHER STUDY

In the course of this thesis research, the author identified several promising areas for future research.

- **Determine how THAAD's cost and schedule performance compare to the cost and schedule performance of other programs that did or did not prototype.**

THAAD has experienced cost and schedule growth. A study should be conducted when the program completes DEM/VAL, which is now projected for 1997. This study should first define if UOES, with its contractor-provided maintenance concept, can be realistically compared with other systems that use the traditional definition of IOC. The study could determine what portion of the cost and schedule growth is attributable to increased requirements, inaccurate estimates, and from programmatic changes. The study could recommend improvements to UOES and ACTD acquisition approaches to help better control cost and schedule risks.

- **Determine the effectiveness of operational prototypes to influence the objective system's design.**

A starting point might be to analyze how these acquisition strategies actually impacted mission effectiveness to determine:

- What are the additional risks associated with fielding a less than mature system?
- What are the recommended management structures used to control these types of programs?
- What is an effective method for collecting and implementing user suggestions?

- **Investigate software reuse across missile defense programs.**

In THAAD, the GBR and the BM/C3I reused a significant portion of existing software code. This investigation could include:

- a comparison of other organization's reuse policy to BMDO's reuse policy.
- a comparison of the architectures other real-time information systems.
- a recommendation for policies concerning missile defense software architecture.

- **Study how to maintain a standardized communication architecture in the rapidly expanding demand for frequency bandwidth.**

THAAD objective system will require more throughput than the current standard Joint Tactical Information Distribution System can provide. This study could include:

- a review of current and projected DOD needs.
- a review of the projected technological break-throughs that DOD communications planners should be prepared for.
- a recommendation for how to efficiently take advantage of technological innovation.

APPENDIX A. DEFINITIONS AND ACRONYMS

DEFINITIONS

Advanced Concept Technology Demonstration - an integrating effort to assemble and demonstrate a significant, new military capability, based upon maturing advanced technology(s), in a real-time operational environment at a scale adequate to clearly establish operational utility and system integrity. The purpose of an ACTD is to address problems in acquisition, system development and product transition. The ACTD approach is designed to transfer mature technologies rapidly from the developers to the users[Ref. 11: p.5]. An ACTD is not an acquisition program, has no firm operational requirements, nor a firm Contingency Operations Plan (CONOPS) [Ref. 37: p. 7].

design - (verb) to make preliminary sketches of, a sketch a pattern, or outline for.
- (noun) a plan; a thing planned for or outcome aimed at. [Ref. 38: p. 373]

effectiveness - the performance or output received from an approach or a program. Ideally, it is a quantitative measure which can be used to evaluate the level of performance in relation to some standard, set of criteria, or objective [Ref. 39: p. B-4].

evaluation - the process whereby data are logically assembled and analyzed to aid in making systematic decisions [Ref. 39: 14-1].

external forces - program factors that lie outside a PM's span of control, although a PM may have some limited influence over these factors. Examples include events, technologies, funding support, or user requirements that are critical to a program's success and influence its direction.

internal forces - any program factor that a PM can directly control.

leverage - to increase the means of accomplishing some purpose, largely through the use of borrowed ideas or technologies.

operational prototype - a prototype that can deliver some degree of useful military capability, but a capability that is less than the full operational capability that is required in the system's Operational Requirement Document [Ref. 37: p. 7].

system - a composite, at any level of complexity, of personnel, procedures, materials, tools, equipment, facilities, and software. The elements of this composite entity are used together in the intended operational or support environment to perform a given task or achieve a specified production, support or mission requirement [Ref. 39: B-12].

User Operational Evaluation System - an operational feature of a program's acquisition strategy that provides for early user involvement to influence the objective system design and may provide for the war-fighter a military useful interim contingency option. A UOES is not an ACTD. A UOES is embedded within an approved acquisition program. The approved acquisition program is based on firm operational and developmental requirements as well as an approved Contingency Operation Plan (CONOPS) [Ref. 37: p. 7].

user - the user is generally regarded as the combat or operator community for which the system is being acquired. The ultimate user is the regional war-fighting Commander's in Chief (CINCs) [Ref. 37: p. 8]

ACRONYM	**FULL TITLE**
ABM	anti-ballistic missile
ACAT	Acquisition Category
ACTD	Advanced Concept Technology Demonstration
ADM	Acquisition Decision Memorandum
ARPA	Advanced Research Projects Agency
ATD	Advanced Technology Demonstration
BM/C3I	Battle Management/Command, Control, Communications, and Intelligence
BMDO	Ballistic Missile Defense Organization
CAD	computer aided design
CASE	computer aided software engineering
CD	Concept Definition
CE/D	Concept Exploration & Definition
CONOP	Contingency Operations Plan
COSTAR	corrective optics space telescope axial replacement
COTS	commercial off the shelf
CPR	Cost Performance
CRC	communication reporting center
CWBS	Contractor Work Breakdown Structure
DACS	divert and attitude control system
DEM/VAL	Demonstration and Validation
DOD	Department of Defense
DSMC	Defense Systems Management College
EMD	Engineering and Manufacturing Development
ERIS	Exoatmospheric Reentry Vehicle Interceptor Subsystem
FFP	Firm Fixed Price
FIST	Flight Projects Office Information Systems Testbed
FPTOC	Force Protection Tactical Operations Center
FTV	flight test vehicle
GBR	Ground Based Radar

GFE	Government Furnished Equipment
GPS	Global Positioning System
HAWK	Homing All Weather Killer
HEDI	High Endoatmospheric Defense Interceptor
HMMWV	High Mobility Multi-purpose Wheeled Vehicle
HOE	Homing Overlay Experiment
HST	Hubble Space Telescope
HWIL	hardware-in-the-loop
ICBM	inter-continental ballistic missile
IDA	Institute for Defense Analysis
ILSP	Integrated Logistics Support Plan
IOC	initial operational capability
IR	infrared
JPL	Jet Propulsion Laboratory
JROC	Joint Requirements Oversight Counsel
JTAGS	Joint Tactical Ground Station
JTIDS	Joint Tactical Information Distribution System
JTMD	Joint Theater Missile Defense
KITE	Kinetic Kill Vehicle Integrated Technology Experiment
KV	kill vehicle
LMSC	Lockheed Missiles and Space Company
LRIP	low rate initial production
MDA	milestone decision authority
MEADS	Medium Extended-range Air Defense System
MFP	Material Fielding Plan
MMIC	monolithic microwave integrated circuit chips
MNS	Mission Need Statement
MS	Milestone
NASA	National Aeronautics and Space Administration
NMD	National Missile Defense
NMD-GBR	National Missile Defense Ground Based Radar
ORD	operational requirements document
PATRIOT	phased-array tracking to intercept of target
PATRIOT PAC-2	PATRIOT Advanced Capability-2
PATRIOT PAC-3	PATRIOT Advanced Capability-3
PEO	program executive office
PLS	Palletized Load System
PM	project or program manager
RDT&E	research, development, test and evaluation
RFP	Request for Proposal
RISC	reduced instruction-set computing
SDC	Strategic Defense Command
SDIO	Strategic Defense Initiative Organization
SEC DEF	Secretary of Defense

SICPS	Standard Integrated Command Post Shelter
SIL	System Integration Lab
SINCGARS	Single Channel Ground and Airborne Radio System
SLA	stereolithography
SPR	Secure Packet Radio
SSA	source selection authority
SSEB	source selection evaluation board
TBM	tactical ballistic missile
THAAD	theater high altitude area defense
TMD	theater missile defense
TMD-GBR	theater missile defense ground based radar
TOC	tactical operations center
TPO	THAAD Project Office
T/R	transmit and receive
TVC	thrust vector control
UAV	unmanned aerial vehicle
UOES	user operational evaluation system
USD (A&T)	Under Secretary of Defense for Acquisition and Technology
USMC	United States Marine Corps

APPENDIX B. RISK MANAGEMENT TERMINOLOGY

Chapter II's outline of Risk Management in DOD is based on DSMC's 1989 Risk Management Guide; THAAD's acquisition strategy was approved in 1992; and the DOD Regulation 5000.2 was updated in 1996. Each document uses slightly different risk management terms. This table summarizes the terms used, and for the objective of this thesis, the one relevant difference is shaded.

DSMC RISK MANAGEMENT GUIDE *1989*	**THAAD ACQUISITION STRATEGY** *1992*	**NEW DOD-R 5000.2** *1996*
FACETS OF RISK		
Technical	Technical	Performance
Programmatic	Programmatic	
Supportability	Supportability	
Cost	Cost	Cost
Schedule	Schedule	Schedule
RISK MANAGEMENT STRUCTURE		
Planning	Planning	Planning
Assessment	Assessment	Assessment
Analysis	Analysis	Analysis
Handling • Avoidance • Control • Assumption • Transfer	Reduction • Mitigation	Reduction • Mitigation

The most important difference is the shift in risk handling activities. The new term for risk handling is "risk reduction," which is accomplished through "risk mitigation." Risk mitigation is a broad term that may include any of the previous techniques of avoidance, control, assumption, and transfer.

Each of these three documents serves a different purpose. DSMC's 1989 document is a comprehensive "Risk Management Guide" and it contains the most detail.

The 1996 DOD-R 5000.2 is another comprehensive document, but its sole purpose is not risk management, and it naturally will not contain as much risk management detail. THAAD's acquisition strategy is of course only concerned with risk management in the THAAD program.

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